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Foreword

The 1994 Record *Public Transportation: Bus, Rail, Ridesharing, Paratransit Services, and Transit Security* reviews new research in the operational and service delivery aspects of public transportation. In each category, new ideas are explored and improved practices discussed. Potential application is real and holds significant promise of utility and better customer service.

The papers are based on presentations at the 73rd Annual Meeting of Transportation Research Board, held in January 1994 in Washington, D.C. Each paper, in accordance with established TRB procedures, has been reviewed by peers (practitioner and academic) in the field of public transportation.

Six operational elements of bus operations are addressed in Part 1. To better serve customers, real-time transfer systems may offer meaningful improvements (Lee and Schonfeld). The Saudi Arabian Public Transportation services are reviewed in terms of performance (AlGadhi). Development of an origin-destination bus route matrix is suggested for model consideration (Navick and Furth). With-flow bus lanes may affect bus travel times (Shalaby and Soberman). Chassis U-bolt connections are important to bus safety (Dusseau et al.), as is research on ways to reduce noncollision passenger injuries (Fruin et al.) and on the impact of weather conditions (Chang and Rogness). Part 2 represents new interest in an earlier technology, the electric trolleybus (ETB). The application of ETB (Guillot and Phifer) and its operation (Boorse) are studied in a variety of conditions. If routes change, ETB wire requirements play an important role (Schwartz).

Part 3 considers regional rail issues for the United States (Schumann and Phraner), low-density areas (Matoff), the San Francisco Bay Area (Payne), and Philadelphia (DeGraw). In Part 4, performance evaluation (Lyons et al.), safety issues (Meadow), and at-grade crossings (Korve and Jones) for light rail are studied.

Part 5, on ridesharing and paratransit, examines several key issues. Understanding special commuting needs is growing in importance (Ho), whereas employer-provided transportation benefits help increase ridership (Beaton et al.). Still, it is a challenge to reduce drive-alone rates (Stewart) and to be cost-effective (Stewart). Commuting stress is real in the Southern California area (Novaco and Collier). An old but reappearing practice, jitneys, requires closer public oversight (Boyle).

Transit security has always been important. Sadly, public perception appears to be that personal security is decreasing, that it is dangerous to ride transit. Statistics suggest otherwise, but improvements are necessary. Maximizing security by the effective use of standard procedures offers assistance (Balog et al.). Even small systems experience a perception of crime (Benjamin et al.). Declining ridership may be attributed to some degree to the perception of crime on bus systems (Ingalls et al.).

The preceding research studies contribute to a wide range of operational subjects. In total, it is a rich vein of original research to be mined by public transportation management, staff, instructors, researchers, and students.

PART 1

Bus Operations

Real-Time Dispatching Control for Coordinated Operation in Transit Terminals

KURT KER-TSUNG LEE AND PAUL M. SCHONFELD

For real-time dispatching control in transit terminals, the holding time for each ready vehicle is optimized on the basis of predicted arrival delays of late vehicles and other factors such as expected transfer volumes and vehicle operating costs. Holding times for each ready vehicle are optimized with the proposed numerical approach, which evaluates the dispatching decision at frequent intervals for ready vehicles by evaluating a dispatching objective function. That function is computed by numerically integrating relevant probability distributions. The numerical results can provide general dispatching guidelines. However, the dispatching algorithms are efficient enough to be used in real time for each decision.

Schedule synchronization may greatly reduce transfer delays at transfer terminals where various routes interconnect. Moreover, probabilistic variations in traffic conditions and dwell times at stations may be accommodated to some extent by including safety factors, called slack times in schedules. However, at the scheduled departure time from a transfer terminal, some connecting vehicles may still be late. For any vehicle that is ready to be dispatched, the question is whether to dispatch it on schedule or to wait for late incoming vehicles with connecting passengers. There is a finite (typically a very small) number of such vehicles, and estimates of their late arrival times are presumed to be available. For example, among three vehicles from three connecting routes, suppose Vehicle 1 is ready on time, Vehicle 2 is 1 min late, and Vehicle 3 is 2 min late. In that case, the dispatching decision for Vehicle 1 has three choices: (a) dispatch immediately, (b) wait 1 min for Vehicle 2, or (c) wait 2 min for both Vehicles 2 and 3. For Vehicle 2, the decision will be to either dispatch immediately or wait another minute for Vehicle 3.

Such choices can be well formulated in objective functions that consider the operator cost of delaying a vehicle, the delay cost to users already on board or waiting downstream, and the missed connection cost to passengers transferring from late incoming vehicles (which depends on the wait time until the next suitable departure). The formulation can be extended to more complex cases involving dispatching with real-time information. In that case, the probability that a late vehicle arrives at the transfer terminal within the time interval of the dispatching decision may be obtained from the conditional probability distribution estimated from real-time information.

Several previous studies have concentrated on control strategies to maintain the reliability of service headways on transit routes. Turnquist analyzed wait time variances at stops along one transit line (*1*). The effects of frequency and reliability on the proportion of random and nonrandom arrivals were explored through a small empirical study. Turnquist also proposed four major classes of strategies to improve reliability: vehicle-holding strategies, reduction in the number of stops made by each bus, single preemption, and provision of exclusive right of way (*2*). This study showed that service frequency is the most important factor to affect the control strategies. Other findings are that for low-frequency service (fewer than 10 buses per hour), schedule-based holding strategies or zone scheduling are likely to work best. For midfrequency service (10 to 30 buses per hour), zone scheduling or single preemption is most effective, although headway-based holding can also work well if an appropriate control point can be found. In a high-frequency situation on the route (more than 30 buses per hour), an exclusive lane combined with single preemption should be considered.

The problem of determining the optimal dispatching decision for a system at a single service point of one or two vehicles is formulated by Osuna and Newell as a dynamic programming problem (*3*). They conclude that the optimal decision will hold a vehicle if it returns within less than about half the mean trip time for a one-vehicle route. However, the optimal decision will control the vehicles so as to retain nearly equally spaced dispatch time for a two-vehicle route.

A computer simulation was developed by Abkowitz et al. (*4*) and used to comparatively evaluate four transfer strategies in a simple two-route case: (a) unscheduled transfers, (b) scheduled transfers without vehicle waiting, (c) scheduled transfers where the lower-frequency vehicle is held until the higher-frequency vehicle arrives, and (d) scheduled transfers where whichever vehicle arrives first waits for the later vehicle. This approach yielded interesting numerical results about the effects of various route characteristics on the preferred strategy. However, a simulation approach is computationally expensive, and the results are subject to the inherent variance of Monte Carlo methods. Henderson et al. used the ratio of how often passengers are late versus how often they are on time as the service reliability measure since it is more meaningful for passengers (*5*).

Strategies for controlling vehicle movements to improve service reliability along transit lines and dispatching decisions at stations have also been analyzed by simulation models. Araya and Sone examined the traffic dynamics of automated transit systems in which a fixed number of vehicles are operated according to a preestablished schedule along a single-loop track with on-line stations (*6*). They executed several simulations to demonstrate the usefulness of the proposed control algorithm. A detailed passenger

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flow model is included in the simulator that gives the exact number of passengers, both in vehicles and at station. Van Breusegem et al. used a complete discrete-event traffic simulation model to determine the controlled speed along the route and the dispatch slack time at the station to guarantee system stability (7). They have developed a complete traffic analysis for open lines and loop lines in the class of sequential lines with or without reference to a nominal time schedule. Simulations have also shown the efficiency of the proposed traffic control algorithms and their robustness against disturbances occurring randomly on a loop line.

Lee and Schonfeld optimized the headways and slack times for the operation of multiple transit routes through a transfer terminal and suggested that real-time dispatching control can further improve such a timed transfer system (*8*).

After a review of these studies, it appears that all previous studies either optimized the preplanned scheduling or analyzed strategies for controlling vehicle movements along one route and for holding vehicles at stations or control points to improve ''headway-based'' reliability and reduce the waiting along one route rather than transfer delays among different routes. These deficiencies limit the applicability of timed transfer operation in transportation system. Therefore, this study focuses on dispatching control based on real-time computations in a transit timed-transfer system.

SYSTEM DEFINITION

Bus routes, rail transit routes, and other kinds of transit routes may be included in any combination in analyzed systems. It should be noted that a real-time holding or dispatching decision is considered only for coordinated transit operation.

It is assumed here that the probability distribution for travel times of late vehicles such as in Figure 1 and the current positions of late incoming vehicles are already known when a holding or dispatching decision is made. A reasonable number of monitoring points may be set up along each route. The travel time distribution from monitoring points to the transfer terminal can be obtained from the data collected at those points. To reduce the costs for data collection, the monitoring points could be set up at intersections with traffic control and bus stops. In normal traffic conditions (i.e., without incidents along the route), the mean and the standard deviation of travel times along the route should increase as the distances to the transfer terminal increase. When a dispatching or holding decision is made, the mean and standard deviation of the travel time from the current estimated position of late vehicles can be estimated. An example of the relations between the travel time and distance of late vehicles along the route is shown in Figure 2.

The holding times for vehicles ready to be dispatched are either continuous or discrete depending on the characteristics of the empirical distributions for late incoming vehicle arrivals. However, the holding or dispatching decision should be updated in every decision interval. If the optimized holding time of a vehicle is 0, that vehicle should be dispatched immediately.

TOTAL COST FUNCTION

From the system definition, a model for dispatching decisions with real-time computation is developed. The objective function is the

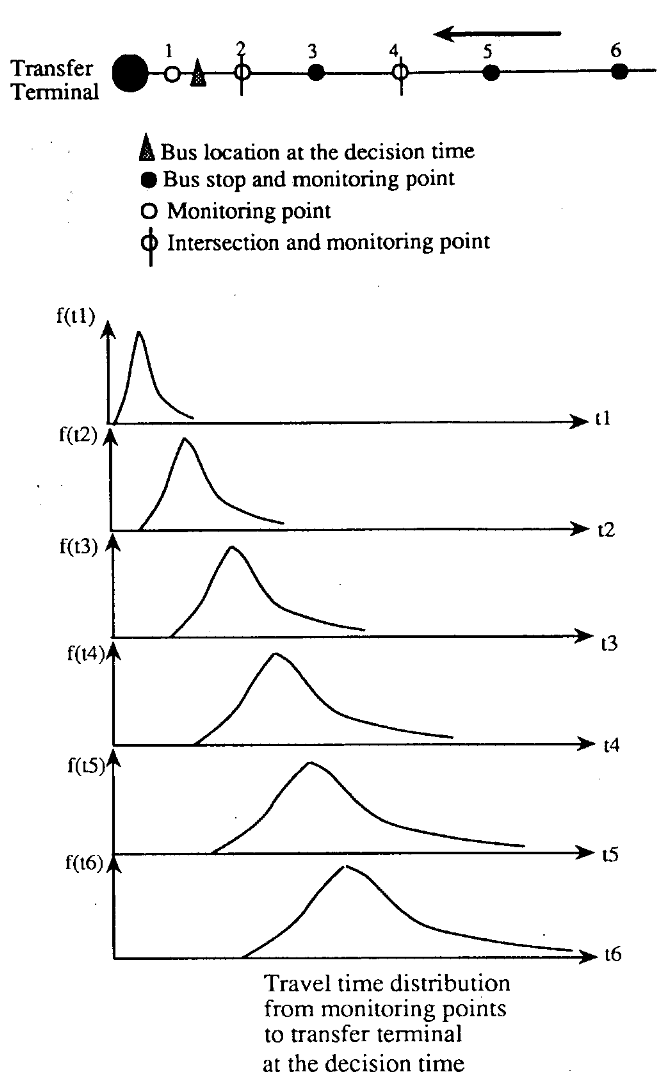


FIGURE 1 Predicted travel time distributions of late incoming vehicles.

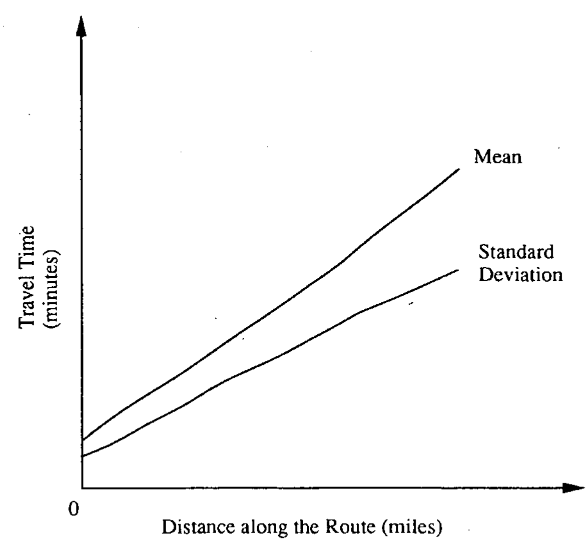


FIGURE 2 Example of interpolation of late vehicle arrival times along route.

total cost associated with holding or dispatching decisions. This cost includes the delay cost to vehicles that are ready to be dispatched and to passengers already on board or waiting downstream along the route and the missed connection cost of late incoming transfer passengers. There will be no further interrelation among the ready routes at the decision time since the connections among them have already been made. Thus, the cost due to holding or dispatching decisions is separable for each ready vehicle. That means that the total cost due to the decisions of all ready routes should be the simple summation of the cost for each ready route. Therefore, the holding or dispatching decisions can be made independently for each ready vehicle.

The total cost for ready Route i due to the decision includes the delay cost for ready vehicles and passengers and the missed connection cost for late incoming transfer passengers.

$$C_i = Y_i + U_i \tag{1}$$

where

C_i = cost due to holding or dispatching decision on Route i (\$),
Y_i = delay cost of holding vehicles that are ready to be dispatched and passengers already on board on Route i (\$),
U_i = missed connection cost of late incoming passengers transferring to Route i (\$).

In each holding or dispatching decision for each vehicle, the delay cost to ready vehicles, to passengers already on board, and to passengers waiting downstream on Route i Y_i can be formulated as

$$Y_i = (Q_{iw} + B_i)\, T_i \tag{2}$$

where

i = route index of ready routes,
Q_i = number of passengers already on board on Route i and waiting passengers downstream along Route i,
T_i = holding time on Route i (min),
u_w = time value of passengers already on board (\$/passenger-min),
B_i = vehicle operating cost on Route i (\$/vehicle-min).

An hourly operating cost function of the type used by Jansson is used here if the vehicle size S_i is used on each Route i (*9*).

$$B_i = a_i + b_i S_i \tag{3}$$

where

a_i = fixed coefficient in vehicle operating cost function on Route i (\$/vehicle-min),
b_i = variable coefficient in vehicle operating cost function on Route i (\$/vehicle-min),
S_i = vehicle size on Route i (seats/vehicle).

Therefore, Equation 2 can be formulated as

$$Y_i = (Q_{iw} + a_i + b_i S_i)\, T_i \tag{4}$$

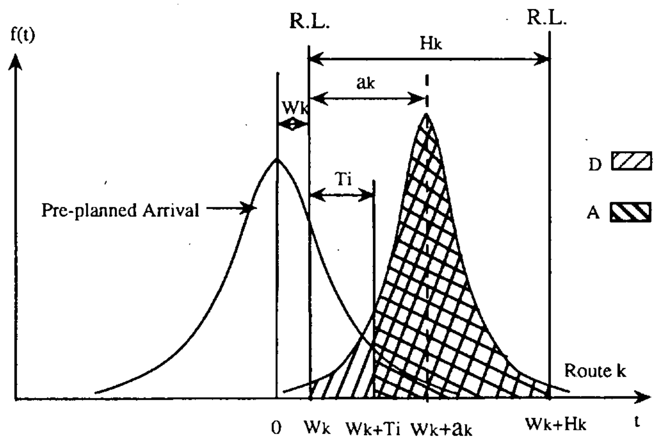
For each dispatching decision, the missed connection cost of late incoming passengers transferring to each ready vehicle i when it was held for time interval T_i is determined from the conditional probability that late incoming vehicles arrive after the holding time T_i. Figure 3 shows this conditional probability in which A indicates the probability that late Vehicle k arrives after T_i and D is the probability that Vehicle k arrives late. Therefore, A/D is the conditional probability that late Vehicle k arrives after T_i when k is already late. The total missed connection cost of late incoming passengers transferring to Route i U_i is then formulated as

$$U_i = \sum_{k=1}^{n_a} q_{ki}\, u_m\, H_i \left[\frac{\int_{w_k+T_i}^{H_k} f(t_k)\,dt_k}{\int_{w_k}^{H_k} f(t_k)\,dt_k} \right] \tag{5}$$

where

k = route index of late routes,
n_a = number of routes with late arrivals,
q_{ki} = transfer passengers from Route k to Route i (passengers),
w_k = preplanned slack time of Route k at the transfer terminal (min),
H_i = headway for Route i (min),
H_k = headway for Route k (min),
t_k = vehicle arrival time on Route k (min),
$f(t_k)$ = probability density function for vehicle arrival time on Route k,
u_m = time value of late incoming transfer passengers (\$/passenger-min).

The passenger volumes on board or waiting downstream can be more accurately estimated with advanced fare collection system



Key:

R.L. : Decision time (latest arrival time to make the connection)
i : Route index for ready vehicles
k : Route index for late vehicles
ak : Mean of late arrival time of route k
Wk : Pre-planned slack time for route k
Hk: Pre-planned headway for route k
A : Probability of late vehicle on route k which arrives after holding interval Ti
D : Probability of vehicle on route k which arrives late
Ti: Holding time on route i
tk : Vehicle arrival time on route k
f(tk) : Probability for tk

FIGURE 3 Conditional probability that late vehicle arrives after holding time.

(e.g., smart cards and electronic fare boxes) in which the origins and destinations of passengers and the boarding time can be obtained automatically and transmitted to the control center. However, without advanced ticketing system, the passenger volumes already on board and the transfer volume of late incoming passengers can be estimated from the vehicle loads, (i.e., the volume multiplied by the headway and the volume of passengers waiting downstream along routes can still be estimated from the volume multiplied by the headway and the holding time).

$$Q_i = \sum_{j=1}^{n_e} q_{ij}H_j + g_i(H_i + T_i) \tag{6}$$

$$q_{ki} = r_{ki}H_k \tag{7}$$

where

n_e = number of routes ready to be dispatched,
q_{ji} = volume of transfer passengers from Route j to Route i (passengers/min),
r_{ki} = volume of transfer passengers from Route k to Route i (passengers/min),
j = route index of ready routes,
g_i = volume of passengers waiting downstream on Route i (passengers/min).

Equations 4 and 5 can be substituted into Equation 1 to determine the total cost due to dispatching decision C_i:

$$C_i = (Q_i u_w + a_i + b_i S_i)\,T_i + \sum_{k=1}^{n_a} q_{ki}u_m H_i \left[\frac{\int_{w_k+T_i}^{H_k} f(t_k)dt_k}{\int_k w_k f(t_k)dt_k}\right] \tag{8}$$

Since the total probability that a vehicle arrives late should be 1 when that vehicle is already late, Equations 5 and 7 can be modified as

$$U_i = \sum_{k=1}^{n_a} q_{ki}u_m H_i\left[\int_{w_k+T_i}^{H_k} f(t_k)dt_k\right] \tag{9}$$

$$C_i = (Q_i u_w + a_i + b_i S_i)T_i + \sum_{k=1}^{n_a} q_{ki}u_m H_i\left[\int_{w_k+T_i}^{H_k} f(t_k)dt_k\right] \tag{10}$$

When the arrival time of late vehicles can be predicted precisely with the advanced real-time information (i.e., deterministic arrival of late vehicles), the only possible candidate holding times for ready vehicles will be the predicted arrival time of each late vehicle Z_k (i.e., possible holding times are discrete rather than continuous). Therefore, the total cost due to dispatching decision C_i can be simplified as

$$U_i = \sum_{k=1}^{n_a} q_{ki}u_m H_i\left[\sum_{tk=w_k+T_i}^{H_k} f(t_k)\right] \tag{11}$$

where

L = route index of late routes in which Z_L is greater than Z_k,
n_b = number of late routes where Z_L is greater than Z_k,
Z_k = predicted late arrival time of Vehicle k, and
Z_L = predicted late arrival time of Vehicle L.

If the arrival times of late vehicles are distributed according to a general discrete distribution, Equations 5 and 8 may be expressed

$$U_i = \sum_{k=1}^{n_a} q_{ki}u_m H_i\left[\sum_{tk=w_k+T_i}^{H_k}\right] \tag{12}$$

$$C_i = (Q_i U_w + a_i + b_i S_i)T_i + \sum_{k=1}^{n_a} q_{ki}u_m H_i\left[\sum_{tk=w_i+T_i}^{H_k} f(t_k)\right] \tag{13}$$

It should be noted that if it is possible to identify unusual delays of late vehicles due to incidents or vehicle breakdowns from the differences of speed or travel time between the previous vehicles and current vehicle along the route, then very useful real-time information can be provided and delay costs to ready Vehicle 4 avoided.

OPTIMAL HOLDING TIME AND DISPATCHING DECISION

After formulating the two components of total cost C_i (Equation 1) as functions of holding time T_i, the optimal value of T_i (i.e., T_i^*, where * indicates optimal value) can be sought numerically since the probability distributions are too complex for analytic integration. Thus, numerical integration of conditional probabilistic vehicle arrival distributions is used to compute the missed connection cost. Such numerical integration is much faster and more precise than simulation. Afterward, the following algorithm is used to make each dispatching decision for ready routes.

The algorithm starts from the ready route with the highest passenger volume already on board, with an initial holding time of 0 to determine the total cost due to that decision using Equation 4. Then for each ready route, holding time is increased until total costs do not decrease further. That determines the optimal holding time. The decision for each ready route should be updated in each decision interval or when new events such as arrivals of late incoming vehicles occur. In normal traffic conditions, the optimal holding time of ready vehicles in the current decision should be smaller than the optimal holding time in the last decision. If that does not happen, one may suspect that incidents are delaying the late vehicles. The steps in this algorithm can be stated as follows:

1. Collect empirical data on travel time distributions along each route in each demand period.
2. Estimate relations for means and standard deviations of those travel time distributions and distances along each route.
3. Estimate the passenger volume already on board, the volume of passengers waiting downstream, and the transfer passenger volumes from late incoming vehicles to ready vehicles at the decision-making time.
4. Estimate the mean and standard deviation of travel time distributions for each late vehicle using the relations developed in Step 2 and the current estimated positions of late vehicles.
5. Start from the ready route with the highest passenger volume already on board with an initial holding time T_i of 0 to determine the total cost due to that decision by Equation 8.

6. Repeat Step 5 by increasing T_i until no lower cost is obtained to determine the optimal T_i^*.
7. Repeat Steps 5 and 6 for every ready route in the order of increasing ready passenger volume.
8. Update the information of Steps 3 and 4 in the next decision interval z.
9. Repeat Steps 5 through 8 for every ready vehicle in each decision interval z.
10. If $T_i^* = 0$, dispatch Vehicle i immediately. Otherwise, hold Vehicle i for another decision interval.

At the conclusion of Step 10, the results include the optimal holding time for each ready vehicle and the dispatch decision. These decisions should be reevaluated in each decision interval.

NUMERICAL RESULTS

Numerical results were computed mainly for the purpose of investigating the sensitivity of optimal holding times for ready vehicles to various factors such as the ratio of time value of passengers already on board to time value of passengers of late incoming transfer passengers, the ratio of passengers volumes already on board to passenger volumes of late incoming transfer passengers, the vehicle operation costs, and the mean and standard deviations of vehicle late arrival times.

Normal distributions are used here for the numerical analysis. However, the proposed optimization models can work with any late arrival distributions identified from real-time information. It should be noted that since travel times must necessarily be positive, arrival time distributions with infinite left tails, and hence with some negative arrival times, cannot strictly represent reality. However, even when such distributions are used to approximate the true late arrival distributions, the probabilities of early arrivals are small enough to be negligible. Of course, if real-time information is used for late arrivals of incoming vehicles, negative arrivals will never appear.

A three-route example is considered in the numerical analysis. The purpose of this example is to explore the relations among variables and particular parameters through sensitivity analysis. However, the holding or dispatching decisions based on real-time computation can be made for relatively large systems. (For practical purposes the number of routes turns out to be unlimited.)

The baseline parameter values were selected for the numerical analysis because they appeared reasonable and typical; they are as follows:

$_i = 1.0$
$\beta_i = 0.667$
$_i = 0.0042$
$_m = 0.2$
$_w = 0.25$

he demand generated randomly and other input data for each oute in the numerical example are shown in Table 1. The transfer assenger volumes for each pair of routes are the

$$_{ij} = Q_iQ_j(1 - p_q)\left[\left(\sum_{i=1}^{n} Q_i\right) - Q_i\right] \tag{14}$$

TABLE 1 Input Data for Three-Route Real-Time Dispatching Decision

Route	Demand (pass./min.)	Headway (min.)	Slack Time (min.)	Mean of Arrival Time (min.)	Standard Deviation (min.)
1	2.5	10.0	0.028	0	0
2	2.0	10.0	0.049	-0.5	0.2
3	1.75	10.0	0.915	-1.0	0.3

where p_q is the percentage of passenger volumes from each route to transfer terminal and Q_j is the total passenger demand on Route j in passengers per hour. With these baseline values, the optimal holding time for Route 1 in the first decision is 1.375 min. The relations between the holding time and the cost components of the cost function due to the first holding or dispatching decision are shown in Figure 4. This figure clearly shows that the optimal holding time represents a trade-off between the dispatching delay cost of ready vehicles and passengers Y_i and the missed connection cost of late incoming transfer passengers U_i. U_i decreases with T_i while Y_i increases constantly with T_i. At high values of T_i, U_i approaches 0 while Y_i still increases. That limits to a finite value of the magnitude of the optimal value of T_i.

The effect of the vehicle operating cost on the optimal holding time T_i^* is shown in Figure 5. It is reasonable that for a given passenger volume, T_i^* should decrease at a decreasing rate as the cost of delaying vehicles increase. Figure 6 shows the effects of standard deviations of late arrival times on optimal holding times. The slopes of the T_i^* curves are determined by the slopes of the normal distributions as standard deviations change. Thus, in Figure 6, T_i^* first increases as the standard deviation increases. At first, the additional uncertainty provides economic justification for a larger safety factor (i.e., holding time). However, as the standard deviation approaches a significant fraction of the headway, it becomes preferable to reduce holding time and allow a higher probability of missed connections in the "tail" of the late vehicle arrivals distribution. Beyond a certain critical standard deviation,

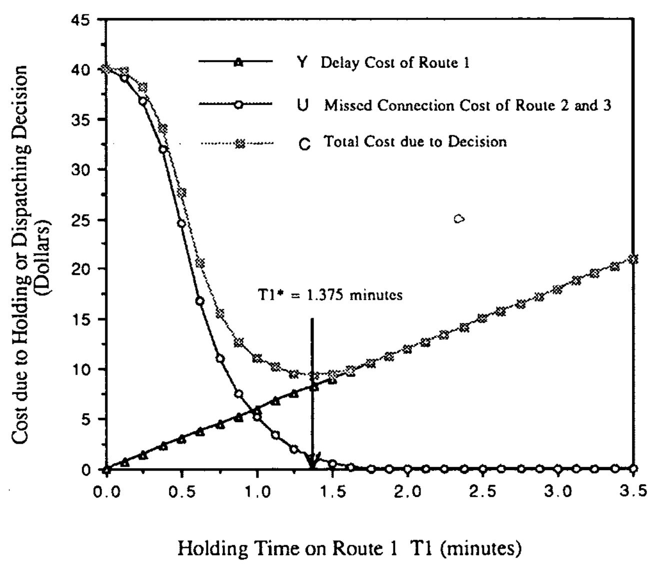


FIGURE 4 Effects of holding time on cost components due to holding in three-route case.

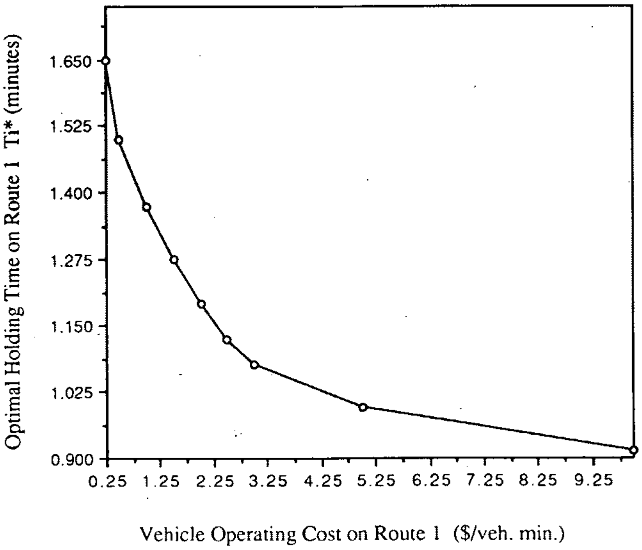


FIGURE 5 Effect of vehicle operating cost on optimal holding time in three-route case.

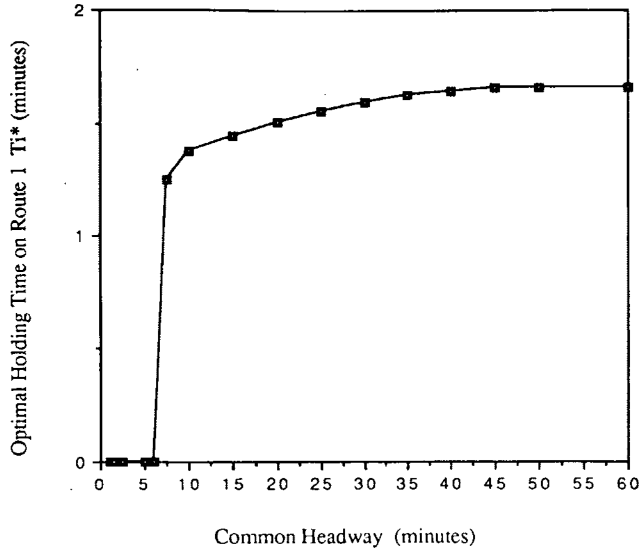


FIGURE 7 Effect of common headways on optimal holding time in three-route case.

the optimal holding time T_i^* should be 0, implying that as vehicle arrivals become more uncertain and headway magnitudes do not produce excessive missed connection costs, it becomes uneconomical to leave any safety factors in the holding or dispatching decision. Conversely, holding times is most feasible and desirable when arrival uncertainties are low. In Figure 7, the optimal holding times are 0 when the common headway is too small to be worth coordinating and increase at a decreasing rate beyond certain critical headways. The reason that the optimal holding time remains constant even when common headway increases significantly is that the probability of missing a connection beyond a certain holding time becomes negligible.

To identify the time series of holding or dispatching decisions for the three-route example, the means and the standard deviations of travel time distributions along each route in each decision interval and the numerical results are given in Table 2. The total

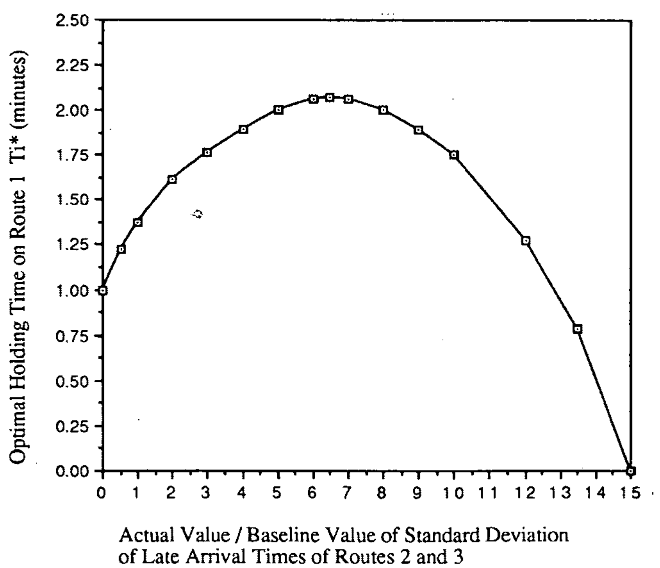


FIGURE 6 Effect of standard deviation of late arrival time on optimal holding time of ready vehicle in three-route case.

TABLE 2 Optimal Results for Preplanned and Real-Time Optimization

Cost	Zero Slack W/O Control	Zero Slack With Control	Optimal Slack W/O Control	Optimal Slack With Control
C_o	36.027	36.027	36.027	36.027
C_w	13.128	13.128	13.128	13.128
C_v	38.189	38.189	38.189	38.189
C_N	89.344	89.344	89.344	89.344
C_s	0	0	3.091	3.091
C_m	12.578	12.578	8.256	8.256
C_d	9.876	9.876	6.678	6.678
C_F	22.454	22.454	18.026	18.026
C	109.798	109.798	105.370	105.370
C_y	0	2.533	0	2.198
C_p	10.672	2.245	8.067	3.981
C_D	10.672	4.778	8.067	6.179
TC	120.470	114.576	113.437	111.549
AC	9.668	9.195	9.104	8.952

C_o = Vehicle Running Cost ($/min.)
C_w = User Waiting Cost ($/min.)
C_v = User In-Vehicle Cost ($/min.)
C_N = Total Non-Transfer Cost ($/min.)
C_s = Slack Delay Cost ($/min.)
C_m = Missed Connection Cost ($/min.)
C_d = Connection Cost ($/min.)
C_F = Total Transfer Cost ($/min.)
C = Total Cost of Pre-planned Optimization ($/min.)
C_y = Holding Cost for Ready Vehicles and Passengers ($/min.)
C_p = Missed Connection Cost due to Dispatching ($/min.)
C_D = Real-Time Control Cost ($/min.)
TC = Total System Cost ($/min.)
AC = Average Cost ($/trip)

holding times for Routes 1 and 2 are 1.14 and 0.66 min, respectively. The total delay cost on Route 2 is \$0.759, and the missed connection cost saved on Route 3 due to holding on Route 2 is \$1.089.

CONCLUSIONS AND EXTENSIONS

Real-time optimization of the holding time for each ready vehicle at a transfer terminal, on the basis of the predicted arrival delays of late incoming vehicles, is proposed to make holding or dispatching decisions. An algorithm reevaluates the dispatching decision at frequent intervals for vehicles that are held. The real-time computation of the objective function is achieved by integrating probability distributions numerically.

Qualitatively, the conclusions from the numerical results may be summarized as follows:

1. Ready vehicles with higher passenger volumes on board should be dispatched immediately when the connecting passenger volume on late vehicles is relatively low.
2. Ready vehicles should be dispatched immediately when the uncertainty about late vehicle arrivals is relatively large.

Possible extensions of the analyses and mathematical models developed in this study may include

1. Applying real data in the numerical analysis to reflect the real arrival patterns,
2. Adapting these models for other types of transportation terminals such as airline hubs, and
3. Applying advanced real-time information from intelligent vehicle-highway systems to improve system operation.

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Evaluation of Performance of Riyadh Urban Public Transportation Services

SAAD A. H. ALGADHI

Private jitneys were the only form of public transportation in Riyadh, Saudi Arabia, and an important part of its transportation scene for many decades. However, when the Saudi Arabian Public Transport Company (SAPTCO) began to operate as the city's subsidized transit company, jitney operators chose to operate only in the profitable corridors and only during periods of peak demand. Thus, SAPTCO had to operate losing routes and services without offsetting revenue from peak periods and heavy-demand corridors. The findings of a study conducted to evaluate the performance of both SAPTCO and jitney services in Riyadh are presented. The annual public transportation ridership is estimated at about 26 million passenger trips, 82 percent of which are carried by minibuses. It appears that the jitney clientele is attracted to the jitneys because they offer service qualities that are lacking in the public transit system, including shorter waiting times, shorter trip times, and a patron's ability to flag vehicles at any street corner and to get off at will. It also appears that SAPTCO cannot operate successfully in the presence of such fierce competition from minibuses. Thus, SAPTCO is not giving intracity services a priority in its operations; instead, it is using its resources in the profitable operations of intercity services and the contracts and chartered bus business. However, poor performance by SAPTCO seems to be a bigger obstacle to successful operation than fierce competition by jitneys. The dilemma facing the city officials is twofold: (a) serving the areas that lost public transportation services, either jitney or SAPTCO; and (b) integrating the jitneys into Riyadh's public transportation system without harming the SAPTCO system.

Urban transportation systems should provide adequate mobility to various locations to satisfy essential human needs. In urban areas, these needs cannot be provided by automobiles without causing severe congestion, pollution, and safety problems. On the other hand, public transit is a relatively high-capacity and energy-efficient alternative for urban passenger transportation as compared with the private automobile. If planned, operated, and managed effectively, transit can serve as an environmental safeguard for conserving energy, protecting community quality of life, and facilitating urban economic growth and development.

Public transportation is usually provided by a single publicly owned system in developed countries; typically, both capital and operating costs are subsidized. Developing countries have much greater diversity in terms of service provision—small private companies often provide a large part of the system capacity under highly competitive and poorly regulated conditions. In other cases, where the political decision has been to keep fares well below costs, a single publicly owned provider may provide fixed-route service with large buses in competition with private operators providing flexible or fixed-route service (or both) with minibuses.

Riyadh, the capital of Saudi Arabia, has experienced a rapid development in the past two decades and currently occupies an area of about 1600 km^2 with a population of about 2 million. Vehicle ownership is about 0.2 vehicles per person, and only 2.8 percent of the city's households are without vehicles (average household size is 6.17). The average trip rate is 2.14 trips per person per day, which is generally lower than what has been reported in U.S. cities, where typical trip rates range from 2.8 to 3.5 trips per person per day. However, this may be misleading since the trip rates for men and women older than 16 in Riyadh are 2.78 and 0.58, respectively. As women are not allowed to drive in Saudi Arabia, they make only 20 percent of the trips per person that men make (*1*).

Moreover, only about 1.6 percent of the total daily person trips are made on public buses, which is typical for an automobile-oriented city; thus transit use is about 0.034 transit trips per capita. Taxis carry only 0.6 percent of the weekday person trips, and the rest are made by private vehicle (*1*).

Before 1979 urban public transportation services in Riyadh were provided by a number of minibuses (25 seats) operated by individual owner-operators (i.e., jitney service.) Minibus drivers operate their buses with no time schedules and make unilateral decisions, with almost no coordination with others in regard to routes served and hours of operation. Thus, the number and frequency of service on any given route can change significantly from one day to the next.

In 1979 the Saudi Arabian Public Transport Company (SAPTCO) was established as the first bus transit company in the country, where the Saudi government owns 30 percent of its shares. Soon after its establishment, it was granted the rights of providing subsidized intercity and intracity public transportation services throughout the country. However, minibuses continued to provide intracity transportation services, successfully competing with SAPTCO on the high-demand routes serving the city center. The number of minibuses increased drastically—from 800 in 1979 to more than 2,600 in 1986, about 900 of which were in Riyadh (SAPTCO, unpublished report, 1992, in Arabic). This increase is thought to be related to the official increase of the government-set fare from SR 1.00 to SR 2.00 per passenger trip in 1983 ($1.00 U.S. = SR 3.75).

SAPTCO started its first route in Riyadh on July 30, 1979, and continued to expand its services to cover different parts of the city (Figure 1). In its first year, SAPTCO ridership was about 8 million passenger trips, which increased steadily to reach about 35 million (on more than 22 routes) in 1982. When the fare was officially increased in 1983, ridership started to decrease drastically. This forced SAPTCO to eliminate some of the nonproductive routes.

The reduction in routes served by SAPTCO, from 22 to 13, has resulted in a concentration of service by both SAPTCO and minibuses on heavy-demand routes only. Consequently, some areas have lost public transportation service. The annual number of per-

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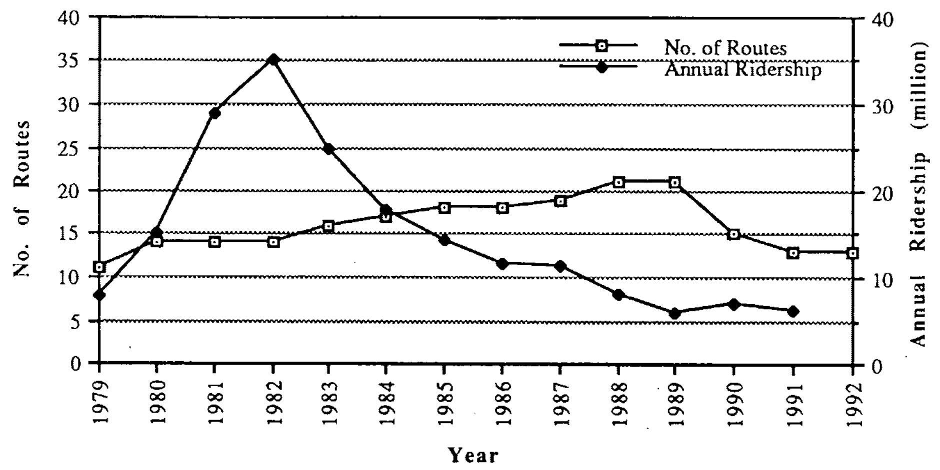

FIGURE 1 SAPTCO intracity service routes and annual ridership in Riyadh (source: SAPTCO).

son trips served in these areas before the service was cut approached 2.3 million passenger trips in 1986 (*1*).

In 1992 SAPTCO was operating 13 intracity routes in Riyadh, radially structured, with a total network length of 578 km and 252 scheduled daily runs. Service operation started at 5:00 a.m. and continued to 11:00 p.m. on most routes, with the scheduled service headway ranging from 6 min on high ridership routes to 1 hr on others. On the network level, the average scheduled peak-period headway is about 15 min, which doubles in the off-peak (peak period is 6:00 to 9:00 a.m. and 4:00 to 11:00 p.m.).

Figures 2 and 3 show the daily and monthly ridership variations, respectively. These figures show that weekend (Thursday and Friday) average daily ridership is higher than that of weekdays and that the patronage drops at the beginning of summer then builds up in fall.

Relevant literature review revealed that few studies were conducted on the performance of public transportation services in Riyadh. Probably the most involved study was that by Arriyadh (Riyadh) Development Authority (*1*). The study estimated that the 1987 daily public transit demand in Riyadh was 74,000 passenger trips, of which SAPTCO carried 35,000 (47 percent) and the Minibus Paratransit System (MPS) handles the rest.

A less detailed (and less reliable) study, which was based on a limited questionnaire survey, estimated that SAPTCO's daily ridership was about 52,000 passenger trips in 1986 and that MPS's daily ridership was 80,000 passenger trips (*2*). A third study, by the Ministry of Communication, estimated the daily public transit demand in Riyadh at about 78,000 passenger trips in 1986 and expected that it will increase at an annual rate of 3.08 percent (i.e., 97,000 passengers in 1992) (*3*).

Finally, a study by Koushki based on a questionnaire survey suggested that only 31 minibuses were operating along eight routes in 1984, with a daily ridership of 11,000 passenger trips (*4*). However, this study is questionable since actual field traffic surveys during the same period showed that the number of minibuses reached 1,016 (unpublished report).

These studies clearly show the intensity of competition that SAPTCO faces from MPS in Riyadh. However, inconsistency is evident among these studies with regard to the magnitude of passenger demand and the contribution of each of the two systems to match that demand. In addition, it appears that an understanding of the characteristics and performance of each of the two systems is lacking.

This paper attempts to evaluate the public transportation services in Riyadh by measuring the performance of each of the two operating systems simultaneously and assessing the impact of jitneys on SAPTCO ridership and revenue. This was done by im-

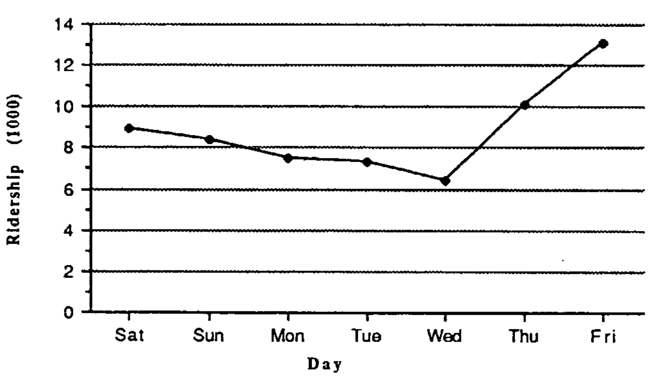

FIGURE 2 SAPTCO intracity service daily ridership variation in Riyadh, May 1992 (source: SAPTCO).

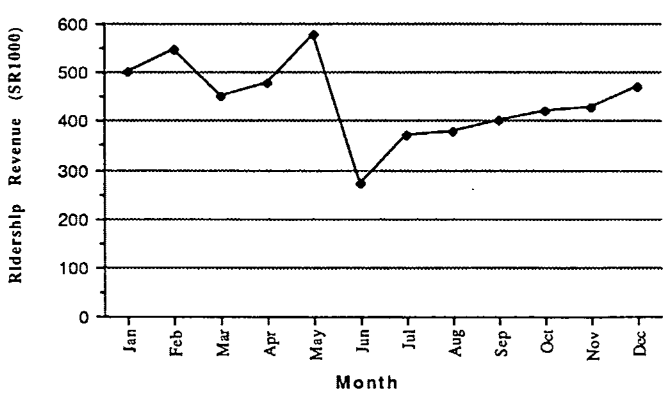

FIGURE 3 SAPTCO intracity service monthly ridership variation in Riyadh, 1992 (source: SAPTCO).

plementing a statistically based data collection program described in the next section. Study findings are presented next, followed by discussion and conclusions.

METHODOLOGY

For the purposes of this study it was necessary to establish the baseline conditions that present a snapshot of the systems' performance at a point in time. These were defined by time of day for each route in the system. Complete route profiles were developed from these data to facilitate comparisons among routes across the two systems. The study protocol is as follows:

1. The first step in the data collection program was to identify the data items required. The data items sought include: peak load, schedule adherence (SAPTCO only), total boarding in passenger trips, female boarding (SAPTCO only), revenue, passenger-kilometers, and boarding by fare category (SAPTCO only; cash or prepaid reduced tickets). Female passengers were singled out because they are only served by SAPTCO, where they have their separate compartment inside the large bus. Each data item is required at the route level for each time period: a.m. peak (6:00 to 9:00 a.m.), base (9:00 a.m. to 4:00 a.m.), and p.m. peak (4:00 to 9:00 p.m.).
2. A sampling plan was then designed incorporating the quantity of data to be collected and the timing of data collection. Two factors were taken into consideration in establishing the sampling plan: the desired accuracy and the inherent variability of the data. Accuracy has two components: a tolerance and confidence level. The tolerance indicates the range around the observed value within which the true value of the data item is likely to lie. The level of confidence indicates the probability that the true value is within the tolerance range around the observed value. In this study, a 90 percent confidence level was used for route-level data and a 95 percent confidence level for system-level data. Because of the lack of historical data, the needed tolerance levels and coefficients of variation were assumed in this study on the basis of default values recommended by UMTA (5).
3. The next step was to choose the data collection technique. Three techniques for positioning personnel and resources in the field for data collection were employed in this study—namely, ride checks, MPS driver questionnaires, and point checks.

–In the ride check technique, a checker was stationed on board the bus as it traveled along the route from the start of its run (for SAPTCO) to completion. A total of 665 SAPTCO trips (119 runs) covering the 13 routes were surveyed in this study; 381 trips (57 percent) were during the weekdays and the rest were on weekends.

–Because of the lack of fixed routes and schedules for the MPS, it was difficult to determine the amount of service and ridership before the on-board survey. This also made it difficult to maintain survey controls with respect to sample data expansion. Therefore, surveys were made to attempt to overcome these difficulties. A questionnaire was designed and conducted with MPS drivers (156 drivers) to determine which routes are the most used, and to estimate the relative use of each route and MPS operating characteristics. In addition, this pilot survey was used to determine the work schedule for the minibus ride checks.

A cordon count survey was conducted at eight locations surrounding the downtown area, continuously over three consecutive days (Friday to Sunday), to count the number of buses entering and leaving the city center. Data from this survey were used as a control for data expansion. In addition the MPS fleet size was established by recording the license plate number of each minibus crossing the cordon boundaries. Local authorities did not have data on the size of MPS fleet.

A procedure similar to SAPTCO's on-board survey was then used to survey minibuses. Surveyors were assigned to a specific route each day, covering one or more time periods. Since an individual minibus may not follow the same route for an entire day, the surveyor was required to inquire about his assigned route until a minibus traveling that route was found. In this manner a total of 434 trips were surveyed (223 trips were on weekdays) over nine main routes served by MPS.

–The third type of data collection technique used was that of point checks, in which a checker is stationed at the roadside and observes buses as they pass by. Ride checks were used mainly to obtain the required sample size of boarding (passenger trips) and passenger kilometers, which cannot be obtained by other survey techniques. Hence, supplementary point checks were needed only for schedule adherence (SAPTCO only), in which the sample size required exceeded that required for total boarding and passenger kilometer data items. It is less costly to gather additional schedule adherence data by using a single point checker than by using onboard checkers. The central SAPTCO station downtown was used for the point check survey.

The data collection program was then scheduled and implemented over 4 weeks during May 1992.

FINDINGS

To minimize the data entry errors, specially designed self-validating data entry screens on personal computers were programmed and used for each type of field survey. The data were then transferred to the IBM 3080 mainframe at King Saud University, and Statistical Analysis System (SAS) software was used for data analysis. In this section the measured performance of SAPTCO service is presented first, followed by that of MPS. A comparison of performance indicators from both systems is also presented.

Detailed baseline data were obtained for each of the 13 routes operated by SAPTCO and the 9 routes operated by MPS in Riyadh, by day type, direction, and time period. However, space limitations prevent these results from being presented here; they can be found elsewhere (*6*). Tables 1 and 2 present summaries of these data at the system level only for SAPTCO and MPS, respectively.

It is evident from Table 1 that SAPTCO carries, on weekdays, an average of about 16,000 daily passenger trips (17,000 on weekends), 11 percent of whom are female passengers. However, only 58 percent of the daily weekday scheduled trips were executed, mainly because of a driver shortage (82 percent of the lost trips). The percentage of lost trips decreases on weekends to about 22 percent. The recovery is attributed to the availability of more drivers on weekends, some of these drivers are assigned to school transportation services during weekdays.

TABLE 1 SAPTCO Service Baseline Data

Item	System Level	
	Weekday	Weekend
1. Routes round trip:		
travel time (min.)	1294	1306
length (km)	578	578
2. Schedule adherence (%):		
On time	50	49
Late	17	16
Early	34	35
3. Fare type (%):		
cash	98	99.5
tickets	2	0.5
4. Headway (min.):		
Scheduled	14	19
Actual	18	16
5. Avg. waiting time (min.)	20	15
6. Daily Passenger-km	120026	143859
7. Daily vehicle-trips:		
Scheduled	1538	1234
Actual	895	948
8. Daily Ridership:		
Passenger-trip	15813	16759
Female-trip	1750	1778

Furthermore, service reliability data show that only 50 percent of the trips adhered to their time schedules (+3 min), while 17 percent were late and the rest left the bus stop early. In addition, a passenger waits an average of about 20 min for the bus on weekdays (15 min for weekends), whereas the average weekday actual headway achieved was about 18 min (16 min on weekends). The average passenger waiting time, $\overline{w}$, is calculated according to the following well-known relation (*7*):

$$\overline{w} = \frac{1}{2} * \overline{h} + \frac{\text{var}(h)}{2 * \overline{h}}$$

where $\overline{h}$ is the average service time headway and var(h) is headway variance.

It is worth noting that the average peak load on any given route or period did not exceed 30 passengers for weekdays and weekends. Meanwhile, 87 percent of SAPTCO's fleet are 42-seat Neoplan buses and the rest are 29-seat Toyota coaster buses. This might indicate the inefficient utilization and mix of the fleet.

On the other hand, the analysis of the MPS driver questionnaire revealed that minibuses operate on nine main radial routes serving the city center. All these routes parallel SAPTCO's fixed routes. The data collected in this study show that minibuses operate 6,000 daily trips, on weekdays, carrying 75,000 passengers—fivefold that served by SAPTCO.

The MPS service is provided by a fleet of 671 minibuses during weekdays. However, the fleet size increases to 1,100 minibuses on weekends, carrying 95,000 passengers a day. This large increase of the fleet size may indicate that many of the minibus owner-operators have other jobs during the weekdays and use their vehicles to generate more income during weekends. Furthermore, this large MPS fleet size resulted in a passenger's average waiting time of 3 min on weekends and 7 min on weekdays.

TABLE 2 MPS Service Baseline Data

Item	System Level	
	Weekday	Weekend
1. Routes round trip:		
travel time (min.)	643	608
length (km)	356	356
2. Headway (min.)	5	3
3. Avg. waiting time (min.)	7	3
4. Daily vehicle-trips	6095	6659
5. Daily Passenger-km	595648	725639
6. Daily Ridership	74357	94661

The systemwide SAPTCO and MPS service performance indicators for May 1992 are given in Table 3. These are categorized into efficiency and effectiveness indicators, which are concerned with produced and consumed output, respectively. In other words, efficiency measures reflect resource usage, and effectiveness measures rate the degree to which the transit service achieves the needs of the riders and the community (*8*).

Efficiency indicators considered in this paper include operation cost, service production, and service reliability measures; effectiveness indicators include revenue and patronage measures. Table 3 indicates that it is about 60 percent more costly to operate SAPTCO buses than the smaller minibuses. However, the operating cost per passenger trip is less for SAPTCO than for MPS (SR 1.47 versus SR 1.54), indicating more efficient utilization of the service produced. This can also be seen from the indicator passenger kilometer per vehicle kilometer, which is 6 for SAPTCO and 4 for MPS.

Meanwhile, the average revenue per passenger trip was only SR 1.39 for SAPTCO, resulting in a revenue cost ratio of 0.94. It is obvious that SAPTCO intracity operations could not even recover the operational cost let alone the capital cost. Revenue per passenger trip should have been close to the fixed flat cash rate of SR 2.00, since excursion ticket passengers were only 2 percent. This low revenue per passenger trip could have happened because of errors in estimating the total revenue or total patronage, or because not all the revenue goes to the fare box. Detailed analysis of the data revealed that there was a leakage in the fare collection system.

Furthermore, it appears that minibuses produce more vehicle trips (and vehicle kilometer) than SAPTCO. This resulted in a shorter service headway and thus less passenger waiting time. SAPTCO service appears to be unreliable; only 50 percent of the trips were on time, and 42 percent of the scheduled trips were not undertaken. The relatively higher level of service provided by MPS might have been the reason behind its having most of the total public transportation patronage in Riyadh.

TABLE 3 SAPTCO and MPS Performance Indicators, May 1992

Indicator	SAPTCO	MPS
Efficiency Indicators		
I. Operation Cost (SR)		
1. cost per veh-hr	27.60	16.90
2. cost per pax-trip	1.47	1.56
II. Service Production		
1. Veh-hr	25,718	217,705
2. Veh-km	549,245	4,596,213
III. Service Reliability		
1. Veh-km lost due to:	227,604	-
driver shortage	186,636 (82%)	-
driver absence	25,037 (11%)	-
other reasons	15,933 (7%)	-
2. Schedule adherence (%)		
on time	50	-
late	17	-
early	34	-
3. Avg. waiting time (min)	17	6
4. Avg. headway (min)	18	3
Effectiveness Indicators		
IV. Revenue		
1. Rev./cost ratio	0.94	1.22
2. Rev./pax-trip	1.39	2.00
V. Ridership		
1. Monthly pax-trips	466,000	2,325,000
2. Monthly pax-km	3,678,000	18,351,000
3. Pax-km per veh-km	6	4

CONCLUDING REMARKS

Private jitneys were the only form of public transportation and an important part of Riyadh's transportation scene for many decades. However, when SAPTCO began to operate as the city's subsidized transit company, jitney operators chose to operate only in the profitable corridors and only during periods of peak demand. Thus, SAPTCO had to operate losing routes and services without offsetting revenue from peak periods and heavy-demand corridors. Consequently, SAPTCO eliminated some of these losing routes and now operates only 13 of the 22 routes it operated in 1988, leaving some potential bus passengers unserved.

This study estimates the annual public transportation ridership at about 26 million passenger trips, 82 percent of which is carried by minibuses. It appears that the jitney clientele is attracted to the jitneys because they offer service qualities that are lacking in the public transit system. These include shorter waiting times, shorter trip times, and a patron's ability to flag vehicles at any street corner and to get off at will.

It also appears from this study that SAPTCO cannot operate successfully in the presence of such fierce competition from minibuses. Thus, SAPTCO is not giving intracity services a priority in its operations; instead it is using its resources in the profitable operations of intercity services and the contracts and chartered bus business. However, poor performance by SAPTCO seems to be a bigger obstacle to successful operation than just fierce competition by jitneys. The dilemma facing the city officials is twofold: (a) serving the areas that lost public transportation services, either jitney or SAPTCO; and (b) integrating the jitneys into Riyadh's public transportation system without harming SAPTCO.

In general, the goal of urban public transportation is to enable all residents to use a safe, effective, and efficient mode of public transportation, especially those who do not have access to private automobiles. Regardless of who provides the service, the objectives should be to increase ridership and provide the service for the public in all city parts with the maximum control of cost (and to generate profit if possible). These two objectives should be concurrently considered and balanced.

Therefore, this study recommends, first, that public transportation services in Riyadh should be organized properly by the regulating authority (e.g., Ministry of Transport). This could be done by regulating the way in which minibuses operate in the city, probably through some sort of a cooperative association coordinating the activities of minibuses, and by dividing the city into two parts to be served by each service system (MPS and SAPTCO).

Second, the performance of SAPTCO should be improved. To do so SAPTCO should deal with intracity public transportation services as an autonomous entity (cost and profit center) with its own resources and establish service objectives that are measurable. Once this is done, service effectiveness and efficiency could be improved, resulting in more ridership, better service coverage, and probably more economical operation.

ACKNOWLEDGMENTS

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Distance-Based Model for Estimating a Bus Route Origin-Destination Matrix

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An origin-destination (O-D) matrix is a valuable tool for bus service planning. Unfortunately this trip table is not commonly available to the planner because of survey costs. However, stop-level on-off totals are often available. Past research has concentrated on using these totals along with a small O-D survey as a "seed matrix" to generate the full O-D matrix. Such a seed is subject to bias and sampling error and also incurs the survey cost. A method is described in which the seed matrix is generated using a propensity function that models the propensity of travel as a function of travel distance. The proposed function is a product of a power term and an exponential term, equivalent to a gamma distribution. When applied to one-directional travel, the gamma seed is shown to be reduced to a power function. The power function exponent is estimated by maximum likelihood for data from bus routes in Boston and Miami and is consistently found to be near 1.0. The gamma seed combined with the biproportional method to match origin and destination totals is shown to be effective in generating O-D matrixes for Boston and Miami routes. In a practical design application, design measures were found to be relatively insensitive to changes in the function parameter.

A route-level origin-destination (O-D) matrix is an important tool of the transit analyst. This trip table contains passengers' trip length data that enables the able analyst to test service improvements such as express, limited-stop, and short-turning services, or combining or splitting routes (*1*). Unfortunately, route-level O-D matrixes are not commonly available because of cost restrictions.

On-off counts, which represent row and column totals of the O-D matrix, are often available because they are used for funding and planning purposes. When on (origin) and off (destination) totals are known, the problem of trip distribution is to determine the matrix $\{t_{ij}\}$ that matches the given on and off totals, that is, that satisfies the constraints

$$\sum_j t_{ij} = t_{i\cdot} \quad \text{for all } i \tag{1}$$

$$\sum_i^j t_{ij} = t.j \quad \text{for all } j \tag{2}$$

where

t_{ij} = number of trips from i to j,
$t_{i\cdot}$ = boardings at stop i, and
$t_{\cdot j}$ = alightings at stop j.

Many solutions meet these constraints. The estimation problem is to find the complying matrix that best fits a "seed matrix" embodying prior information about the preferences of trip makers. Two main features distinguish trip distribution models. The first is the source of the seed matrix. The literature on trip distribution for general transportation planning emphasizes two sources of the seed: old surveys and, with the gravity model, distance-based models of impedance or its inverse, propensity. The literature on bus route O-D matrix estimation concentrates primarily on using data from a small O-D sample as the seed. This paper follows the example of an SG Associates study done of Cleveland bus routes in using a distance-based propensity (*2*).

The second main feature of a trip distribution model is the criterion of what constitutes a good fit to the seed, and therefore how the seed should be expanded to match the row and column totals. Methods of expanding the seed that have been studied include the biproportional method (*3*), least squares (*4*), and iterative methods based on maximum likelihood (*3,5*), maximum entropy (*6*), and minimum information (*7*). As Ben-Akiva et al. demonstrate, results for transit route O-D matrixes are extremely insensitive to the method of expansion (*3*). They recommend the biproportional method because of its computational advantages. Another advantage of the biproportional method is that it is compatible with the gravity model of trip distribution.

BIPROPORTIONAL METHOD AND GRAVITY MODEL OF TRIP DISTRIBUTION

The biproportional method produces estimates that have the form

$$t_{ij} = s_{ij} A_i B_j \quad \text{for all } i, j \tag{3}$$

where A_i and B_j are endogenous row and column factors that balance the matrix, that is, enable it to satisfy Equations 1 and 2. There is no general method for solving for these factors in closed form. The most popular way of finding them is through a procedure known variously as iterative proportional fit (*3*) or Bregman's balancing method (*7*), in which all the rows are proportionately factored to match their row totals, all the columns are factored likewise, and the process is repeated until it converges. Convergence is guaranteed, and the resulting matrix solution is unique (*7,8*). If a_i^k is the balancing factor for row i at iteration k, then $A_i = \Pi_k a_i^k$, and similarly for the column factors.

In trip distribution using the gravity model, the seed matrix is a matrix of propensities (reciprocal of impedance or friction) that are primarily a function of distance; that is,

$$s_{ij} = p(d_{ij})\, K_{ij} \tag{4}$$

where

d_{ij} = distance from i to j (km or min),
$p(\,)$ = propensity function, and

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K_{ij} = an empirical adjustment factor, set equal to 1 in the absence of special information.

The doubly constrained gravity model (so called because both origin and destination totals are given) is usually expressed as a share model, sometimes called the interactance model (*9*):

$$t_{ij} = t_{i\cdot} \frac{X_j s_{ij}}{\sum_{j'} X_{j'} s_{ij'}} \quad \text{for all } i, j \tag{5}$$

where X_j is an endogenous factor for column j. There is no general closed-form solution for X_j. The typical solution algorithm begins with $X_j = t_{\cdot j}$, the total attractions at j. Equation 5 is applied to generate a trial matrix. The share form implicitly guarantees that Equation 1 is satisfied, but Equation 2 generally is not. The adjustment is then to multiply each X_j by the ratio (target column j total)/(current column j total). The procedure iterates, repeatedly generating a new trial matrix and adjusting all the column factors until it converges.

Although the doubly constrained gravity algorithm differs from iterative proportional fit, both procedures, in fact, produce identical results (ignoring roundoff error and premature termination). To demonstrate this, one can simply express Equation 5 in the following form:

$$t_{ij} = s_{ij} W_i X_j \tag{6}$$

where $W_i = t_{i\cdot}/(\Sigma_{j'} s_{ij'} X_{j'})$ is a row-specific factor, not dependent on any particular column, that, like X_j, is endogenous to the procedure. Equation 6 is a biproportional form: the product of a cell-specific seed, a row-specific factor, and a column-specific factor. Because the biproportional solution is unique, the doubly constrained gravity model is therefore equivalent to the biproportional model. Each W_i and X_j is equal at convergence to its corresponding iterative proportional fit factor A_i and B_j except for a scalar (the solution will be unchanged if the row factors are all multiplied by a scalar and the column factors divided by the same scalar). Therefore, the biproportional method can be interpreted as a gravity model, in which A_i and B_j are the true "masses," that is, the inherent productiveness and attractiveness of origin i and destination j, and s_{ij} is the inherent propensity of travel from i to j. The interaction of these three factors determines the number of trips from i to j. Unfortunately, because of this interaction, none of the factors can be observed directly.

SOURCES OF SEED MATRIX

In most of the literature on estimating bus route O-D matrixes, the seed matrix is the data from a small-sample O-D survey. This data source has three shortcomings: the survey cost, nonresponse bias, and bias and imprecision due to small sample size. Nonresponse bias occurs when the passengers who do not respond follow different travel patterns than responding passengers. Such a situation arises when response rate is affected by passengers not getting a seat, passengers making short trips, and buses passing through neighborhoods of varying levels of literacy or cooperation. Imprecision is a common problem with small samples. A rule of thumb is that there ought to be at least five counted passengers in an O-D cell for it to be statistically significant. When no passengers are counted in a cell, problems in updating occur—especially when the biproportional method is used in which a cell with a zero seed will remain zero after updating, biasing the results. Although Bayesian methods have been developed for such nonstructural zero cases (*3*), the estimates are still heavily influenced by the empirical seed's patterns. Aggregating to the segment level before updating can also introduce large biases in favor of intrasegment travel (*10*). Historically, problems of nonresponse and small samples have constantly plagued transit O-D surveys, and updating surveys to reliable on-off totals has not eliminated the problem. Resulting O-D surveys still suffer from a lack of believability.

Another possible seed is a "null seed" of equal values (for convenience equal to 1) for all O-D pairs except for O-D pairs that are not valid, whose values are 0. In the bus route problem, an O-D pair is not valid if it represents travel in the wrong direction or if it is on the matrix diagonal. It is also possible to disqualify O-D pairs that represent very short trips if the analyst believes that no one would make a trip that short. Furth and Navick (*10*) show that a null seed with biproportional updating is equivalent to a procedure developed by Tsygalnitsky (*11*), a single-pass recursive algorithm in which all passengers eligible to alight are deemed equally likely to alight at a particular destination. A passenger is eligible to alight if he or she has not yet alighted and has met the minimum distance qualification. Tsygalnitsky's method showed good results at the stop level, even on routes with a significant amount of turnover (*11,12*).

The null seed is plea of ignorance, assigning equal propensity to all valid O-D pairs. However, when on-off totals are given, it is often an effective plea, as it will often outperform a small sample seed. Furth and Navick found that, even without accounting for nonresponse bias, prediction accuracy was better using the null seed than with a small sample seed with a sample size of 100 responses (*10*). Geva et al. also found that it was the absolute sample size and not the sampling ratio that strongly influences estimation accuracy (*5*).

This research, more fully documented by Navick (*13*), was motivated by the desire to develop a more believable and more accurate seed matrix than a null seed without using a small-sample survey. Sometimes there are analysis problems in which an O-D survey cannot be taken and a seed matrix is needed, as in the problem of updating a ride check with multiple point checks (*14*). An analogous development has occurred in modeling O-D flows through intersections. Although various updating methods were developed (the same methods used with transit O-D matrixes), the only options for a seed matrix were either a small sample or a null seed using citywide averages of proportions of vehicles going left, through, and right (*15*), until a model of propensity was developed on the basis of explanatory factors such as intersection angle and competing shortcuts (*16*). Intuitively, the factors that best explain transit trip distribution are a preference for short trips (due to the disutility or travel time), competition with walking for very short trips, price, and effects of competing transit services. Because of the prevalence of flat fares, the price effect has been ignored. The effects of competing services can best be modeled as a modification to an initial framework of an isolated route. The remaining two factors then suggest that propensity be a function of distance, starting off low, increasing as walking loses its appeal, and then decreasing as the trip length disutility begins to overcome the utility of the trip purpose. The Cleveland study found that the trip length distribution followed this pattern (*2*). A gamma

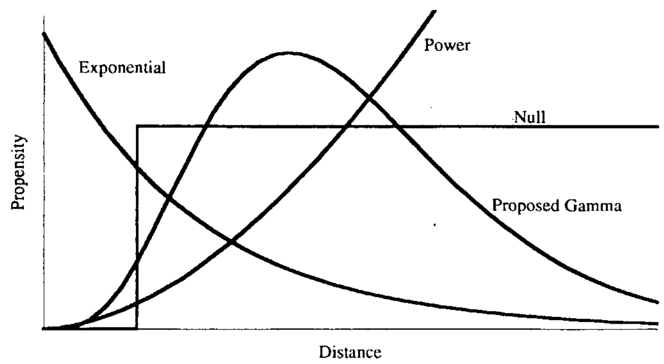

FIGURE 1 Propensity functions.

distribution with $\alpha > 0$ has the desired shape, having the form

$$s_{ij} = d_{ij}^{\alpha} e^{-d_{ij}\beta} \tag{7}$$

Propensity is relative and, unlike a probability distribution, is not required to integrate to 1 because it will only be rescaled in the updating process. Therefore the gamma function scalar needed for a probability distribution may be omitted. The gamma propensity can be thought of as a product of a power function and exponential function. It is illustrated in Figure 1, where it is compared with the null seed, an exponential propensity (if $\alpha = 0$), and a power function propensity (if $\beta = 0$). This propensity function has been used in vehicle trip distribution. Bellomo et al. found the gamma to be a very good fit to automobile trips in Detroit (*17*), and Nihan used it in a gravity model to distribute vehicles along a freeway given ramp on-off volumes (*18*).

"NO QUESTIONS ASKED" SURVEY

The authors' primary source of data for estimating and validating the propensity model was a set of O-D matrixes for three Boston area bus routes. To minimize the effects of nonresponse and sample size bias, a "no questions asked" survey (*11,19*) was conducted on three Massachusetts Bay Transportation Authority (MBTA) routes that have little competition from other transit routes and much passenger turnover. To ensure data quality, the authors were directly involved in data collection and compilation, supervising a team of engineering students.

As passengers boarded, they were handed a card coded with their origin stop number and were asked to simply return the card to a surveyor on leaving the bus. To the authors' knowledge, this is the first application of the "no questions asked" survey at the stop level rather that at the segment level. To get stop-level detail, three surveyors were needed for each bus, two at the front and one at the rear door. At the front door, the first surveyor held a box containing the survey cards, one bunch for each origin stop. Also in the box was the return bunch, consisting initially of specially colored header cards, one per stop (coded by stop number). The first surveyor kept the stop list and made sure that the second surveyor had in hand the bunch of cards for the origin stop being approached. He handed a card to each boarding passenger and collected cards from the alighting passengers. The collected cards were filed by the first surveyor in the return bunch behind the header card of the alighting stop. The rear door surveyor also collected and filed cards from alighting passengers. By being well-prepared and aggressive, the group of surveyors was able to get a response rate of more than 90 percent on every trip, even though two of these routes operate in inner-city areas where typical on-board surveys get a 30 percent response rate. Such a small number of passengers refused to participate that it was possible in most cases to "follow" them and handle their cards for them. The authors' experience with the "no questions asked" survey was very positive, and they enthusiastically recommend it as the best way to directly obtain O-D data when it can be done.

O-D data were also obtained for several Miami bus routes collected using "no questions asked" surveys. In Miami the cards were coded by route segment rather than by stop. Each segment was about 1.6 km (1 mi) long. Table 1 presents the Boston and Miami routes selected for analysis.

NORMALIZED TRIP PROPENSITIES

O-D matrixes obtained from the MBTA surveys were used to investigate the shape of the propensity distribution. These O-D matrixes contain information about propensity and about the popularity of origins and destinations. To uncover the propensity the matrixes had to be normalized, that is, the popularity factor had to be minimized. For example, although it is assumed that propensity to travel eventually decreases as distance increases, a strong attractor such as a mall or rapid transit station at the end of a route may overcome the propensity decay. This attractive power will be reflected by a large number of alightings at the end of the route and should not be mistaken as a desire for longer trips.

Normalizing a matrix usually means updating each row and column total to the same constant, but this is not appropriate for a one-directional, and therefore triangular, matrix in which there are many cells with zero propensity. Therefore each row and column total was normalized to equal the number of valid cells contributing to it, making the average normalized value per cell unity. Any normalized value above 1 implies a greater-than-average travel propensity; values below 1, a smaller-than-average propensity. Matrix cells of equal travel distance were then aggregated within each bus trip and over all bus trips within a route. Because stop spacing does not vary much on the routes studied, travel distance was simply measured in stops. Then aggregating over all the Boston routes, the mean normalized propensity for each travel distance was determined.

A plot of the mean normalized propensity versus travel distance is shown in Figure 2. It supports the assumption of a gamma propensity, showing an increasing propensity for approximately the first seven stops, a leveling off until approximately Stop 27 [about 6.4 km (4 mi)] and then a decay until the end of the route. However, the routes surveyed were only about 8.1 km (5 mi) long, and so further exploration with longer routes is needed to see whether the decay is significant.

ESTIMATION OF PROPENSITY MODEL

Maximum likelihood can be used to estimate the parameters of the gamma propensity function. Each cell of the O-D matrix can be considered an independent Poisson variable T_{ij} with expected

TABLE 1 "No Questions Asked" Survey Data

City	Route	Direction	Period	Trips	Passengers
Boston	1	in	AM	2	176
			PM	1	54
		out	AM	2	129
			PM	1	61
	66	in	AM	4	244
			PM	2	102
		out	AM	4	333
			PM	2	183
	77	in	PM	3	81
		out	PM	3	158
Miami	53	in & out	PREAM	n.a.	255
			AM		377
			MID		573
			PM		0
			EVE		0
			SAT		972
			SUN		195
	54-6	in & out	PREAM	n.a.	896
			AM		1,371
			MID		4,156
			PM		2,630
			EVE		1,902
			SAT		620
			SUN		1,549
	G	in & out	PREAM	n.a.	88
			AM		846
			MID		1,875
			PM		222
			EVE		293
			SAT		1,628
			SUN		1,044

n.a. = data not available

value λ_{ij}. If it is assumed that passengers arrive at stop i in a Poisson process, a typical assumption, and they are "stamped" with their destination stop j with conditional probability $p_{j|i}$, then the number of trips in cell (i, j) will be Poisson distributed. (Alternatively, one could simply assume that passengers arrive in a Poisson process for each O-D pair.) The probability of a realization t_{ij}, given it came from such a distribution, is

$$P[T_{ij} = t_{ij}] = \frac{\lambda^{t_{ij}} e^{-\lambda_{ij}}}{t_{ij}!} \quad (8)$$

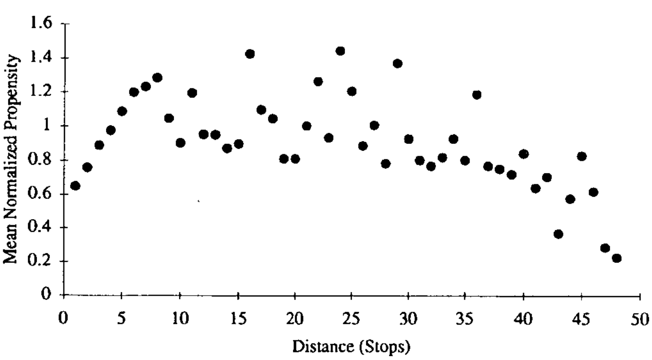

FIGURE 2 Mean normalized propensities for Boston routes.

Each λ_{ij} represents the mean number of trips between origin i and destination j and is assumed, following the gravity model, to be the product of three factors: a productiveness factor A_i, an attractiveness factor B_j, and a distance-based propensity:

$$\lambda_{ij} = s_{ij}(d_{ij})A_iB_j = d_{ij}^{\alpha}\, e^{-d_{ij}\beta}A_iB_j \quad (9)$$

The likelihood function, L, is the probability that the observed matrix is a realization of independent cells that are each Poisson distributed with parameters λ_{ij} that are a function of the parameters A_i, B_j, α, and β:

$$L = \prod_i\prod_j \frac{\left(d_{ij}^{\alpha}e^{-d_{ij}\beta}A_iB_j\right)^{t_{ij}} e^{-(d_{ij}^{\alpha}e^{-d_{ij}\beta}A_iB_j)}}{t_{ij}!} \quad (10)$$

As is common in maximum likelihood estimation, the log likelihood function, LL, is maximized:

$$LL = \sum_i\sum_j \{t_{ij}[\alpha\ln(d_{ij}) - d_{ij}\beta + \ln(A_i) + \ln(B_j)] - d_{ij}^{\alpha}\, e^{-d_{ij}\beta}A_iB_j - \ln(t_{ij}!)\} \quad (11)$$

To maximize the log likelihood function, partial derivatives with respect to α, β, A_i, and B_j are set equal to 0:

$$\frac{\partial LL}{\partial \alpha} = \sum_i \sum_j \ln(d_{ij})(t_{ij} - d_{ij}^{\alpha} e^{-d_{ij}\beta} A_i B_j) = 0 \tag{12}$$

$$\frac{\partial LL}{\partial \beta} \sum_i \sum_j d_{ij}(d_{ij}^{\alpha} e^{-d_{ij}\beta} A_i B_j - t_{ij}) = 0 \tag{13}$$

$$\frac{\partial LL}{\partial A_i} = \sum_j \left[\frac{t_{ij}}{A_i} - d_{ij}^{\alpha} e^{-d_{ij}\beta} B_j\right] = 0 \tag{14}$$

$$\frac{\partial LL}{\partial B_j} = \sum_i \left[\frac{t_{ij}}{B_j} - d_{ij}^{\alpha} e^{-d_{ij}\beta} A_i\right] = 0 \tag{15}$$

Rearranging the partial derivative expressions for A_i and B_j:

$$\sum_j t_{ij} = t_{i.} = A_i \sum_j d_{ij}^{\alpha} e^{-d_{ij}\beta} B_j = \sum_j s_{ij} A_i B_j = \sum_j \lambda_{ij} \tag{16}$$

$$\sum_i t_{ij} = t_{.j} = B_i \sum_i d_{ij}^{\alpha} e^{-d_{ij}\beta} A_i = \sum_i s_{ij} A_i B_j = \sum_i \lambda_{ij} \tag{17}$$

Equations 16 and 17, equivalent to Equations 1 and 2, will be satisfied by updating the seed matrix $\{s_{ij}\}$ using the biproportional method to match the given row and column totals $t_{i.}$ and $t_{.j}$. Notice that this biproportional application arises without explicit constraints that the matrix of estimates $\{\lambda_{ij}\}$ agree with any row or column total.

Investigation of the partial with respect to β reveals that the problem can be further simplified for this one-directional bus route problem. For an upper triangular O-D matrix,

$$\begin{aligned}\frac{\partial LL}{\partial \beta} &= \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} d_{ij}(d_{ij}^{\alpha} e^{-d_{ij}\beta} A_i B_j - t_{ij}) \\ &= \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{d}_{ij}(\lambda_{ij} - t_{ij})\end{aligned} \tag{18}$$

Separating the expression,

$$\frac{\partial LL}{\partial \beta} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} d_{ij}\lambda_{ij} - \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} d_{ij} t_{ij} \tag{19}$$

For the one-directional case, the distance between any O-D pair (i,j) can be expressed as the sum of the distances of stop-to-stop segments:

$$d_{ij} = \sum_{k=i}^{j-1} d_{k,k+1} \tag{20}$$

Substituting

$$\frac{\partial LL}{\partial \beta} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \sum_{k=i}^{j-1} d_{k,k+1}\lambda_{ij} - \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \sum_{k=i}^{j-1} d_{k,k+1} t_{ij} \tag{21}$$

Changing the summation order,

$$\frac{\partial LL}{\partial \beta} = \sum_{k=1}^{n-1} d_{k,k+1} \sum_{i=1}^{k} \sum_{j=k+1}^{n} \lambda_{ij} - \sum_{k=1}^{n-1} d_{k,k+1} \sum_{i=1}^{k} \sum_{j=k+1}^{n} t_{ij} \tag{22}$$

Combining under a single summation,

$$\frac{\partial LL}{\partial \beta} = \sum_{k=1}^{n-1} d_{k,k+1}\left[\sum_{i=1}^{k} \sum_{j=k+1}^{n} (\lambda_{ij} - t_{ij})\right] \tag{23}$$

In this final expression, each k defines a rectangular block of O-D cells representing all of the O-D pairs that cross the segment between stop k and stop $k+1$. Since the sum of any such block is simply the volume on segment $(k,k+1)$, Equation 23 may be rewritten as

$$\frac{\partial LL}{\partial \beta} = \sum_{k=1}^{n-1} d_{k,k+1} \sum_{i=1}^{k} [(\lambda_{i.} - \lambda_{.i}) - (t_{i.} - t_{.i})] = 0 \tag{24}$$

since $\lambda_{i.} = t_{i.}$ and $\lambda_{.i} = t_{.j}$ for all i (Equations 16 and 17). This implies that β and the exponential term of the gamma propensity seed do not affect the likelihood function for the case of one-directional travel. Arbitrarily setting β to 0 allows the seed to be expressed simply as a power function alone:

$$s_{ij}(d_{ij}) = d_{ij}^{\alpha} \tag{25}$$

This result is not an indication that a power seed represents the propensity of travelers—a decay in propensity as distance increases is definitely believed; however, an exponential decay cannot be identified in a one-directional scenario.

The insignificance of the exponential term in the one-directional case can also be proved directly from a property of the biproportional method. A biproportional update $\{\lambda_{ij}\}$ of a seed matrix $\{s_{ij}\}$ will have the following cross-product property (*3*) for cells (i,j) and (u,v) with $s_{ij} > 0$ and $s_{uv} > 0$:

$$\frac{s_{ij}s_{uv}}{s_{uj}S_{iv}} = \frac{\lambda_{ij}\lambda_{uv}}{\lambda_{uj}\lambda_{iv}} \tag{26}$$

Inserting the gamma propensity seed along with the row and column updating factors,

$$\frac{s_{ij}s_{uv}}{s_{uj}s_{iv}} = \frac{(d_{ij}^{\alpha}e^{-\beta d_{ij}}A_iB_j)(d_{uv}^{\alpha}e^{-\beta d_{uv}}A_uB_v)}{(d_{uj}^{\alpha}e^{-\beta d_{uj}}A_uB_j)(d_{iv}^{\alpha}e^{-\beta d_{iv}}A_iB_v)} \tag{27}$$

Collecting terms and canceling the updating factors,

$$\frac{s_{ij}s_{uv}}{s_{uj}s_{iv}} = \frac{(d_{ij}d_{uv})^{\alpha}e^{-\beta(d_{ij}+d_{uv})}}{(d_{uj}d_{iv})^{\alpha}e^{-\beta(d_{uj}+d_{iv})}} \tag{28}$$

In the one-directional case, the following relationships between stops must hold: $i < j$, $u < v$, $u < j$, and $i < v$; otherwise one or more of the seeds in Equation 26 will be 0. Therefore $i < u < v < j$. By placing this relationship on a number line, it is observed that

$$d_{ij} + d_{uv} = d_{uj} + d_{iv} \tag{29}$$

The exponential terms in Equation 28 will therefore cancel for any values of ß, implying that the value of ß is immaterial for the case of one-directional travel.

EQUIVALENCE OF EXPONENTIAL AND NULL SEEDS

A common propensity function used in gravity models is the exponential function. For example, Sheffi derived the maximum entropy result for the doubly constrained gravity model and found the propensity to be exponential (*20*). If α is set equal to 0, the proposed gamma propensity seed becomes an exponential seed. The foregoing results shows that the β does not affect the matrix estimate for one-directional travel. Now if β is set equal to 0, the seed becomes the null seed. Therefore, in the case of one-directional travel, the null seed, which assumes equal propensity for any travel distance, is equivalent to an exponential seed, which implies equal conditional propensity. That is, the propensity for ending a trip at the next stop, given that it has not yet ended, does not change with distance. This extends the result found by Furth and Navick (*10*) and proves that with one-directional travel, Tsygalnitsky's method, the biproportional/gravity method with a null seed, and the biproportional/gravity method with an exponential seed are all equivalent.

MAXIMUM LIKELIHOOD ESTIMATES OF ALPHA

Using one-directional data from Boston, ß could not be estimated. Using the power seed and the likelihood function given earlier, α was estimated from both the Boston and Miami data. The data were first analyzed on a disaggregate level. For each trip, the log likelihood for values of a ranging from -1.0 to 4.0 with a step size of 0.2 was computed, and the optimal α identified. This enumeration method was chosen to allow for aggregation over routes and time periods.

The Miami data were in a two-directional, segment-level format that called for slight changes in the methodology. To place the matrixes in one-directional triangular form, the diagonal cells were split in half for each direction. Also the seed matrix had to be changed because of the diagonal being included in the analysis. Propensity assignment to each cell of the segment-to-segment matrix was the average of the stop-to-stop propensities included in that cell. Maximum likelihood estimation for α was then applied as in the Boston case.

The results of the maximum likelihood estimation are presented in Table 2. The table is aggregated at the route, city, and two-city levels for various periods. As a broad observation, $\alpha = 1.0$ fits all the combinations reasonably well. An attempt was made to observe varying travel propensities at different times of the day and days of the week. No patterns emerged; parameter values were scattered about 1.0 for a.m., p.m., weekday, and weekend trips. This result differs significantly from the exponent of -1.8 estimated in the Cleveland study (*2*) (the reported exponent is $+1.8$, but that is the exponent for impedance, the reciprocal of propensity). In that study, stop-to-stop "distance" was measured as the sum of travel time and route headway. But, more important, that study did not control for alighting totals, and therefore its propensity function is dominated by the decay in the trip length distribution.

Two hypothesis tests were conducted to investigate the statistical strength of a universal alpha. Two proposed universal alphas—1.0 (propensity increasing linearly with distance, in addition to an unspecified exponential decay) and 0 (the null seed, or merely exponential decay)—were tested for equivalence against the maximum likelihood estimate for each particular case. The likelihood ratio test with 1 degree of freedom and a significance level of 0.05 was used. A rejection of the hypothesis implies a poor fit for the so-called universal alpha. $\alpha = 1.0$ was not rejected in 38 percent of the 42 cases, while the null seed was rejected in all except two cases.

Although the performance of the $\alpha = 1.0$ seed is not staggering, consideration must be given to the likelihood of almost any hypothesized value being rejected when there is a large sample size. For model application, a planner must typically choose a value of α without the benefit of data from which to estimate a locally preferred value. Overall, the results show enough consistency and support for a value near $\alpha = 1.0$ that this value is recommended until and unless analysis of additional data points to a preferred value.

PREDICTION ACCURACY AND SENSITIVITY

Using on-off totals for each MBTA trip surveyed, O-D matrixes were estimated for using various universal alphas and compared with the observed matrix. A planner will typically care more about segment-level accuracy than a stop-level accuracy, since misallocating passengers from one stop to a neighboring stop is usually inconsequential. Therefore the stop-level estimated and observed O-D matrixes were aggregated to the segment level using five-

TABLE 2 Maximum Likelihood Alphas

	Period							
Route	AM	Mid	PM	Sat	Sun	WkDay	WkEnd	Day
Bos 1	1.0	n.a.	1.6	n.a.	n.a.	1.0	n.a.	n.a.
Bos 66	1.8	n.a.	0.8	n.a.	n.a.	1.4	n.a.	n.a.
Bos 77	n.a.	n.a.	1.0	n.a.	n.a.	n.a.	n.a.	n.a.
Mia 53	2.4	1.8	n.a.	2.0	0.4	n.a.	2.0	n.a.
Mia 54-6	0.8	0.6	1.6	-0.8	0.6	1.2	0.4	1.0
Mia G	0.6	0.4	0.2	0.6	0.8	0.4	0.6	0.6
Bos	1.4	n.a.	1.0	n.a.	n.a.	1.2	n.a.	n.a.
Mia	0.8	0.6	1.4	0.4	0.8	0.8	0.6	0.8
Bos-Mia	1.0	n.a.	1.4	n.a.	n.a.	0.8	n.a.	n.a.

n.a. = data not available

TABLE 3 Segment-Level Accuracy

	Relative Root-Mean-Square Error (%)							
	Boston Route 1				Boston Route 66			
Alpha	In/AM	In/PM	Out/AM	Out/PM	In/AM	In/PM	Out/AM	Out/PM
0	1.54	2.15	1.72	1.64	0.80	0.98	1.14	1.36
1	1.72	1.79	1.64	1.52	0.68	0.88	0.92	1.39
2	2.03	1.73	1.83	1.59	0.82	1.06	0.97	1.59
optimal	1.61	1.75	1.70	1.52	0.72	0.86	0.94	1.37

stop segments. The matrixes were then compared using the following relative root-mean-square error (*RRMSE*) formula:

$$RRMSE = \frac{1}{t_{..}} \sqrt{\frac{\sum_{i=1}^{m} \sum_{j=i}^{m} (\lambda_{ij} - t_{ij})^2}{K}} \quad (30)$$

where

i,j = segments,
m = number of segments,
K = number of valid segment-level O-D pairs, and
$t_{..}$ = total boardings for trip.

This measure describes the difference between the generated segment-level O-D cell value and the observed cell in relation to the total boardings. The results are given in Table 3 for different values of α. The results show little sensitivity to α, with the measure of error varying between 0.68 and 2.15 percent of total boardings. Of several proposed universal alphas including the null seed ($\alpha = 0$), $\alpha = 1.0$ performs the best in all but three of the cases. The *RRMSE*s for $\alpha = 1.0$ do not significantly deviate from those of the optimal values, with an average error of approximately 1.5 percent over all the routes.

To examine the distribution of errors, the relative absolute error for each (segment-level) O-D cell was calculated using the formula

$$(\text{Relative absolute error})_{ij} = \frac{|\lambda_{ij} - t_{ij}|}{t_{..}} \quad (31)$$

A cumulative distribution of relative absolute errors was constructed over all the route-direction-period combinations. The median relative absolute error was 0.5 percent of total boardings, and the 95th-percentile value was approximately 2.6 percent of total boardings. Both the segment-level and the stop-level errors appear quite reasonable from a planning standpoint.

SENSITIVITY ANALYSIS FOR DESIGN APPLICATION

Another test of a model for generating O-D matrixes is how it will perform under practical design applications. One application in which the O-D matrix is an important tool is the design of limited-stop service to complement local service. A limited-stop route is effective where the route is composed of a few heavily used stops. By combining local service with limited-stop route, where stops are made only at those with the most passenger movements, passenger travel times, and sometimes vehicle operating hours can be reduced.

In our application, those stops in the top 20th percentile by passenger movements were designated as limited stops. All passengers whose origins and destinations were both within one stop of a designated stop were assumed to use the limited stop; the others remained on the local route. In this way, the O-D matrix is split into two. The key design measures for a limited-stop route are peak volume (which governs the cost of the route) and total boardings (which governs the benefit of the route).

Both the observed and estimated O-D matrixes were analyzed for limited-stop service on MBTA Routes 1 and 66 for both directions and in various periods. The results show no practical differences in the design measures for α = 0.0, 1.0, 2.0, and the optimal alpha. Compared with the design measures obtained using the observed O-D matrix, the greatest errors occurred on RT 66/OUT/AM; these errors were 13 boardings per hour (5 percent) and 18 passengers per hour (11 percent) in peak volume. RT 66/OUT/PM had a discrepancy of 14 passengers per hour (7 percent) in peak volume. For the other six route/direction/periods examined, the errors were considerably smaller.

CONCLUSIONS

Through the separation of observed O-D matrixes into two components, propensity and popularity, the gamma distribution was found to be a good representation of passenger trip length. Normalized propensities increased for approximately 1.6 km (1 mi), leveled off for the next 4.8 km (3 mi), and decreased to the end of the route. This model of propensity coupled with the belief in the gravity model enables an O-D matrix to be generated effectively to match on-off counts. The updating method used was the iterative proportional fit, which was shown to be the equivalent of the gravity (share) model.

The gamma propensity function is reduced to a power function in the one-directional case because of the properties of the biproportional method. The exponential term is unobservable in this case, although still a propensity component. Following from this finding, the null seed and the exponential seed, both based on assumptions of equal propensity, were shown to be equivalent in the one-directional case.

The power function's parameter, α, was estimated using the O-D data from both the Boston and Miami routes. In general, α = 1.0 was observed to fit all combinations of routes, days, and times reasonably well. Statistically, a universal α = 1.0 performed better than the null seed ($\alpha = 0$) as measured by the likelihood ratio tests. A test of segment-level accuracy revealed that $\alpha = 1.0$ performed the best, yielding an *RRMSE* in the estimate of a segment-to-segment O-D pair of approximately 1.5 percent of total boardings. For an individual stop-level O-D cell, the median absolute relative error for $\alpha = 1.0$ was approximately 0.5 percent of total boardings. These error magnitudes appear reasonable for planning purposes. In a practical application, limited-stop route design, the design measures were insensitive to the choice of α.

The one-directional nature of this problem limits the degrees of freedom and allows for little variability in final matrix estimation. However, a planner that has on-off totals can now confidently investigate potential route changes in the office using a generated O-D matrix from a power seed with $\alpha = 1.0$ (propensity increasing linearly with distance) rather from an expensive O-D survey. However, care must be taken in applying this method when there is significant competition between routes, as mentioned elsewhere (*10*); competition will lower the propensity to travel between common stop pairs on both routes.

Finally, a methodology has been developed to extend this work to the generation of O-D matrixes for transit networks. In this two-directional problem, the exponential term of the gamma propensity seed will contribute significantly and must be estimated. The two-directional propensity's power term should not vary significantly from the findings in this study.

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Effect of With-Flow Bus Lanes on Bus Travel Times

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Improvements in bus performance due to introduction of reserved bus lanes have traditionally been evaluated in terms of savings in total travel time. Little attention is usually paid to changes in individual segment times (i.e., travel times between consecutive bus stops along the bus route). An approach is presented that investigates the effect of an urban reserved bus lane on bus travel time on individual segments. Subsequently, the change in segment time is related to characteristics and traffic regulations at respective segments. Data were obtained by analysis of videotapes recorded before and after the introduction of exclusive curb bus lanes on a major arterial road in downtown Toronto. The data indicate that time savings are most likely to occur on segments where buses previously experienced considerable congestion, as well as at traffic signals, especially when bus stops are arranged with one on the near side and the next on the far side of their respective intersections. However, these time savings generate additional ridership, resulting in longer dwell times at stops and a corresponding overall increase in total travel time. Thus, the perception of transit service improvement may have more impacts on ridership change than any substantive change in performance. The results of the study suggest opportunities for using reserved bus lanes on a more selective basis along a particular route and the need to reconsider whether taxis should be permitted to use these lanes.

Throughout North America, reduced dependence on public transit has led to increased road congestion with corresponding delays and costs. For example, the daily cost of delay in the United States in 1984, on the freeway system alone, is estimated to have exceeded \$1.2 billion (*1*). By contrast, for any reasonable load factor, buses contribute relatively little to congestion. According to one study, a bus can carry 20 times as many passengers as a car and contributes only 3 times as much to congestion (*2*). As a result, bus priority schemes have attracted attention as a means of reducing bus delays due to traffic congestion in order to enhance the attractiveness of transit.

Although there are a variety of bus priority schemes, this paper is concerned with urban streets along which curb lanes are devoted to bus use, referred to as "with-flow bus lanes." The implementation of such preferential treatment is generally believed to result in an improvement in total bus travel time, taken as the best single indicator of level of service. Previous applications of with-flow bus lanes have shown a wide range of changes in total travel time.

For example, a dual-width exclusive bus lane was introduced on Madison Avenue in midtown Manhattan and before and after observations were obtained for the entire length of this facility (*3*). During the p.m. peak hour, average total travel time decreased by 45 percent, from approximately 18 min to less than 10 min. Canadian examples include bus lanes on Albert/Slater and Rideau streets in Ottawa and Eglinton Avenue in Toronto, where changes in total travel time ranged from 0 to 15 percent, 5 to 25 percent, and 7 percent, respectively (*2*). Discrepancies in the results of these and other studies provide few guidelines for the expected change since, generally, the overall evaluations do not examine the impact on individual segments (i.e., sections between consecutive bus stops). An extensive overview of bus priority experiences in North American and European cities is presented elsewhere (*2,4*).

In this study, the impact of with-flow bus lanes is investigated by analyzing segments of a bus route individually. An attempt is made to relate changes in any one segment to traffic regulations and characteristics of the particular segment.

To study the effect of with-flow bus lanes on travel times, it is essential to analyze conditions both before and after implementation of the priority scheme. This can be accomplished by preparing time-space tables from which travel times for each segment can then be extracted. In obtaining the comparison results, statistical tests should be used to determine whether the difference is significant or whether the change could have occurred simply because of inherent variations. This is the approach used in comparing before and after observations for the Bay Street Urban Clearway in Toronto.

BAY STREET URBAN CLEARWAY AND DATA COLLECTION

Street and Service Characteristics

Bay Street, one of the central corridors in downtown Toronto, extends north-south from Davenport Road to Queens Quay, as shown in Figure 1. There are two lanes in each direction. Transit service consists of two overlapping bus routes, a main route supplemented by a "short turn" route during morning and evening peak periods. In the morning period, most riders board buses at Bloor Street, transferring from the subway to access employment activities to the south. In the afternoon, the direction of flow reverses.

Most of the 17 bus stops covered by the service are located on near sides of signalized intersections, and a few are located on far sides (Figure 2). Throughout this paper, bus stops are by default located on near side (at traffic signals), unless otherwise stated.

Project Implementation

On October 29, 1990, the city of Toronto initiated the dedication of curb lanes to buses, taxicabs, right-turning vehicles, and bicy

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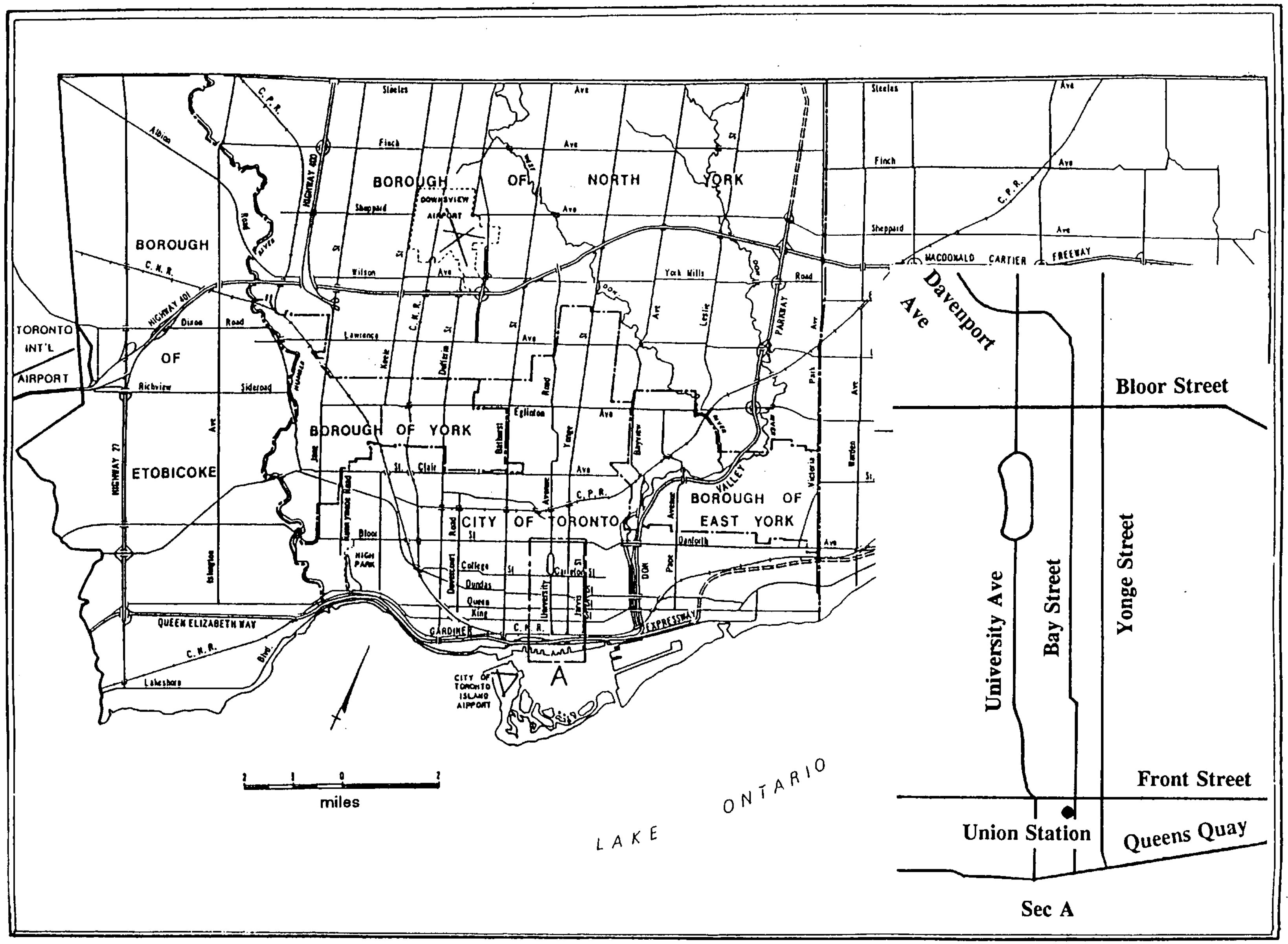

FIGURE 1 Bay Street in metropolitan Toronto.

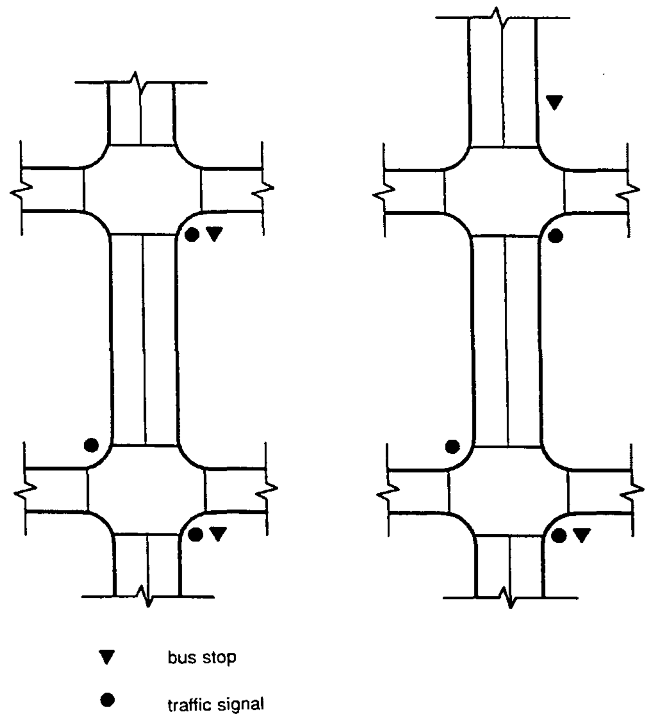

FIGURE 2 Illustration of segments with different bus stop locations.

cles. The project is documented by the Department of Public Works (*5*) and summarized as follows:

1. Almost 3 km of the southbound and northbound curb lanes on the Bay Street are reserved for public transit motor vehicles, taxicabs, right-turning vehicles, and bicycles only from 7:00 a.m. to 7:00 p.m. except on Saturdays, Sundays, and public holidays. Seventeen bus stops in each direction are served by the reserved lanes. There is no break during the off-peak period because bus delays during this period are of the same order as those during the afternoon peak period (*5*).
2. Stopping, except for transit vehicles, is prohibited from 7:00 a.m. to 7:00 p.m. except on Saturdays, Sundays, and public holidays. Parking is prohibited at all times on both sides of Bay Street. Stopping was permitted before implementing this project at all times, but parking was permitted during off-peak periods only.
3. Some new turn prohibitions were introduced.
4. The reserved lanes are identified by overhead signs and pavement markings of white painted diamonds with the message 7 A.M.–7 P.M., MON–FRI, NO CARS–TRUCKS.

Data Collection

Data were collected by continuous on-board video camera filming through the bus windshield. The camera is equipped with a stopwatch that indicates elapsed time, thereby allowing the travel time by segment to be determined.

Before implementation, the operation of traffic control devices (i.e., turn prohibitions and parking) varied throughout the day. Traffic flows and ridership also vary by time of day, as well as by direction. For these reasons, filming was carried out both before and after implementation at three fixed times, namely, 8:00 a.m., 2:00 p.m., and 4:30 p.m., to represent the morning peak, off-peak, and evening peak periods, respectively. For each period, one southbound and one northbound trip were filmed per day. Filming was carried out on Tuesdays, Wednesdays, and Thursdays to avoid irregularities usually associated with weekends, Mondays, and Fridays. The sample sizes for the before and after periods are presented in Table 1.

Data Preparation

From the data collected, each of the southbound and northbound trips during the three periods (i.e., morning, off-peak, and evening), before and after project implementation, was separated into individual dwell times (at each stop), individual travel times from each stop and/or traffic signal to the following stop and/or traffic signal, and individual signal times (i.e., delay time at each traffic signal). Finally, the data were entered for computer analysis.

ANALYSIS OF AGGREGATE TIMES

Before turning to the detailed analysis of segment times, this section examines the change in bus performance on the basis of total travel time. Total travel time for a southbound trip is defined as the time from the moment that doors open at the Bloor bus stop to allow for passenger boarding and alighting until the moment that doors are closed at the Union Station bus stop in the south. Most origins and destinations of passenger trips lie along this section. Total travel time for a northbound trip is defined similarly.

Total travel time includes total running and total dwell times. The change in total running time is considered a better measure of change in overall performance than total travel time because total travel time may increase because of increases in dwell time attributable to increased ridership (which itself, of course, is a positive result).

To study the change in any of these three time measures after project implementation, the *t*-test on two population means is

TABLE 1 Sizes of Before and After Samples

	Number of Trips					
	Morning		Mid-day		Evening	
Period	SB[a]	NB	SB	NB	SB	NB
'Before'	16	13	8	7	14	14
'After'	12	12	10	9	7	10

[a]SB = Southbound; NB = Northbound.

used. The *t*-test was carried out at a 5 percent level of significance as recommended for traffic studies (*6*). The results of all tests are given in Table 2 and discussed here by direction of travel. The mark (√) in the tables indicates that the null hypothesis tested is rejected at the 5 percent level of significance, implying that the random variable has either decreased or increased.

Southbound Direction

Table 2 indicates that the means of total travel time and total running time decreased significantly during the three periods studied. However, because of road construction activity that affected travel times at southern segments before project implementation, the changes in total travel and total running times for the southbound direction do not represent the effect of the reserved lane alone on bus performance. In other words, without this construction activity, travel times before project implementation would undoubtedly have been lower than those recorded.

As indicated in Table 2, the mean of total dwell time increased by 44.8 percent during the midday period, with no significant changes occurring during other periods. The increase in total dwell time is attributable to increased ridership. To investigate the increase in ridership, the numbers of passengers boarding and alighting at each stop were observed. Passengers board from the front door and alight from either the front or rear doors. Since filming was carried out from the front seat, passengers boarding and alighting from the front door were videotaped and subsequently counted when the tapes were viewed. The number of passengers alighting from the rear were counted manually at each stop and dictated into the camera microphone during taping. Figure 3 depicts the changes in ridership, measured by the total number of on-passengers per bus trip along the bus lane for four of the six cases studied; ridership in the other two cases is minimal. The exhibit shows a general increase in ridership that agrees with the findings of another study that reported an overall increase in ridership by 25 percent (*7*). During the midday period, ridership in the southbound direction increased by 45.7 percent, from 45.8 to 66.7 on-passengers per trip, as shown in Figure 3.

Northbound Direction

Since traffic in the northbound direction had not been affected by construction, the results shown in Table 2 for this case provide a more reliable measure of the impact of the reserved lane on the overall bus performance. As shown, during the morning and midday periods, none of the means of the three variables changed significantly after project implementation. During the morning period, traffic is very light in the northbound direction and parking along Bay Street was already prohibited before the bus lane was introduced. Thus, the results pertaining to this period agree with the a priori expectation of changes in the three variables.

Although parking was permitted during the midday period before project implementation, the expected improvement in bus performance after introducing the exclusive lane, accompanied by parking prohibition, did not occur. Total dwell time did not change significantly, yet ridership shows an increase comparable to the case of midday, southbound period, as shown in Figure 3.

During the evening period, the mean of the total travel time increased significantly by 7.4 percent, while the mean of the total running time remained unchanged. However, the mean of the total dwell time increased by 61.8 percent, which explains why the mean of the total travel time increased. Corresponding increase in ridership is shown in Figure 3.

Conclusions Related to Aggregate Times

The results for the northbound direction during the evening period reveal the weaknesses of studying the change in bus performance

TABLE 2 Results of *t*-Tests on Aggregate Time Means

	Morning							
	Southbound				Northbound			
	$\bar{x}_1$[a]	$\bar{x}_2$		Change (%)	$\bar{x}_1$	$\bar{x}_2$		Change (%)
Total Travel Time	18.2	17	✓	-6.7	15.1	14.8		
Total Running Time	13.9	12.2	✓	-12.2	12.3	11.9		
Total Dwell Time	4.3	4.8			2.8	2.9		
	Mid-day							
Total Travel Time	21.5	18.2	✓	-15.3	17.4	173		
Total Running Time	18.2	13.4	✓	-26.2	14.2	12.6		
Total Dwell Time	3.3	4.8	✓	+44.8	3.3	4.6		
	Evening							
Total Travel Time	20.5	18.2	✓	-11.6	19.3	20.7	✓	+7.4
Total Running Time	17.1	14.1	✓	-17.8	15.5	14.6		
Total Dwell Time	3.4	4.1			3.7	6.1	✓	+61.8

[a] $\bar{x}_1$ and $\bar{x}_2$ are sample averages (in minutes) 'before' and 'after', respectively.

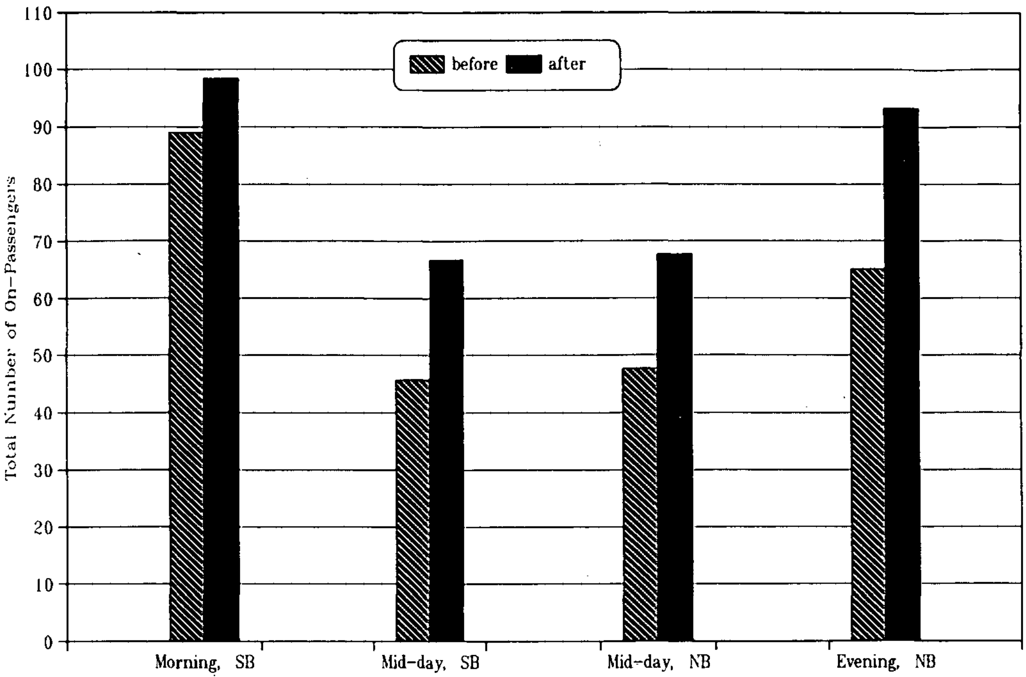

FIGURE 3 Average total number of on-passengers per trip along the bus lane.

on the basis of total travel time change. According to the analysis, bus performance during the evening period deteriorated significantly, after introducing the bus lane, whereas the mean of the total running time, a more precise measure of bus performance, did not change.

For the northbound direction, results indicate that total running time did not change after project implementation during any of the periods studied. The reasons for this result are unclear since, thus far, the impacts of the reserved bus lane on individual segment running times have been ignored. Clearly, measuring total travel time alone does not help explain differential changes in the two basic components (total running and total dwell times). Moreover, total running time does not account for different segment characteristics along the entire route.

CHANGES IN SEGMENT TIMES

Segment time is the time taken to travel between two successive bus stops, excluding dwell time. For a single segment, it is the elapsed time from when the doors are closed at the upstream stop until they are opened at the next stop. Signal time (i.e., bus delay at a traffic signal) is included if encountered during this period. t-tests are carried out for all segment times of southbound and northbound trips during the three periods studied. The results for segment time means that changed at the 5 percent significance level are presented in Table 3. The detailed analysis and results are presented more fully elsewhere on a segment-by-segment basis, for each direction, and by the three basic periods (A. S. Shalaby, unpublished data). Only a few of the more general observations are summarized herein.

Construction, as noted previously, was taking place at a southern intersection on the Bay Street before lane introduction. As a result, the four southbound segments that were affected are discarded from the analysis, except for the morning period when southbound traffic is relatively light at that particular section of Bay Street.

Bus time mean, in the southbound direction during the morning period, decreased significantly after project implementation at only 5 of the 15 segments studied, as indicated in Table 3. Parking and turning prohibitions at these five segments were already in force before lane introduction. Inspection of these segment times shows that most savings occurred at four traffic signals. Examples include signal times, which decreased from 21.7 to 3.2 sec and from 12.1 to 0.4 sec.

TABLE 3 Results of *t*-Tests on Segment Time Means

	Sample Average (sec)		
	'Before'	'After'	Change (%)
Southbound, Morning	48.6	38.2	-21.4
	26.7	23.1	-13.5
	47.7	28.1	-41.1
	23	19.4	-15.6
	70	61.7	-11.8
Southbound, Mid-day	86.5	51.5	-40.5
	44.7	26.6	-40.5
	45.2	58.5	+29.4
Northbound, Evening	66.1	85.6	+29.5
	68.2	31.4	-53.9
	121.1	77.4	-36.1

At one signalized intersection, where the bus stop is on the near side, before lane introduction, buses would usually encounter large queues that would prevent buses from boarding passengers during the red signal. As a result, buses would generally join the queue until it dissipated, board and alight passengers during the green signal, and were then forced to wait during the following red time. After lane introduction, queues are much shorter than before and formed by light-volume, right-turning vehicles Thus, buses can make use of the red signal to board and alight passengers; consequently, the need to wait for more than one red signal becomes less likely.

The phenomenon of time savings at traffic signals is more pronounced when the location of bus stops is such that one on the near side with the following stop on the far side of their respective intersections, an arrangement known as Von Stein's law of transit stop locations (*8*). The bus stops at four consecutive intersections to the north of Bay Street constitute a series of alternative stops. The results show that time means at two of the three segments decreased significantly, mainly because of shorter delay times at traffic signals, as noted earlier. This phenomenon also occurred at the second series of alternative stops at three intersections south of the Bay Street. It is more pronounced when right-turning traffic is either prohibited or very light.

During the midday period, travel time mean decreased at one segment and increased at another, as shown in Table 3. Inspection of the first segment indicates that the significant decrease in segment time mean is due to parking prohibition after lane introduction. Although traffic congestion due to parking was also pronounced at another segment during the before period, change in the segment time mean was obscured by illegal parking and stopping because of ineffective police enforcement after lane introduction at that segment. When delays due to illegal parking and stopping (by cars, taxis, etc.) were eliminated from observations (e.g., waiting time for a bus behind a vehicle stopping or parking was excluded from observations), segment time mean decreased significantly by 40.5 percent.

The significant increase in time mean in the other segment, during the midday period in the southbound direction, is attributed to the considerable increase in signal time mean at the upstream intersection (2.2 to 17 sec), which may be a result of the increase in dwell time at the near-side bus stop, causing buses to wait more often during the red signal after using the green time for boarding. Automobile volume, measured for both directions combined at that segment, was reported to have increased after project implementation by 13 percent, from 1,310 to 1,480 (*7*).

In three of the six cases studied—namely, southbound-evening, northbound-morning, and northbound-midday—buses at the 16 segments of the route experienced no significant change in travel time mean. In one case, although parking prohibitions were applied after lane introduction, there was no effect on bus performance, largely because of relatively light traffic. In the other two cases, parking and stopping regulations were similar before and after, while some new turn prohibitions were introduced after lane introduction. However, no improvement occurred because of light traffic. It is concluded, therefore, as might be expected, that dedication of the curb lane for transit use has no effect on segment times when traffic volume is light, even though turning movements, stopping, and parking prohibitions favor bus performance.

As noted earlier, traffic flow in the northbound direction represents the peak flow during the evening period. Most riders board buses at the southern stops, where major employment centers are located, and alight at the northern segments, especially at the Bloor stop, which is a transfer point between bus and subway services. The results given in Table 3 indicate that bus time mean increased at 1 and decreased at 2 of the 16 segments studied. The increase in segment time mean is due to considerable increase in time mean (44.2 to 61.3 sec) for the traveled distance of this segment (i.e., the segment time excluding the signal time at the upstream intersection). In fact, thorough inspection showed that the number of right-turning vehicles at the downstream intersection increased considerably, leading to longer queues that delayed buses after lane introduction. The increased number of right-turning vehicles is possibly due to the prohibition on right turns at the Bloor intersection and, consequently, the shift of right-turning movements to other intersections. Furthermore, according to one study, the number of taxis increased by 8 percent on the Bay Street to take advantage of the reserved lane (*7*). Thus, taxis attracted from alternatives to the Bay Street cause high delays at intersections where they leave for their destinations.

Introduction of the bus lane, together with the prohibition of right turns at one intersection, relieved to a large extent the considerable delays experienced by buses in the two northern segments where significant decrease in time mean occurred. The bus stops in the two consecutive segments are alternate, which also contributed to time savings, as explained earlier.

Effect on automobile times in non-bus-lanes as well as surrounding streets was reported to be insignificant, except in six sections, one in Bay Street and five in neighboring streets, where travel time decreased significantly (*7*).

SUMMARY AND RECOMMENDATIONS

Change in bus performance, following the introduction of with-flow bus lanes on urban streets, has usually been evaluated on the basis of total travel time change. This paper shows that total travel time is not the best measure of change in bus performance because its components (i.e., running times and dwell times) may vary considerably. Total running time also attributes the change in performance to the overall characteristics of the street, with no focus on individual segments having different characteristics and traffic regulations. As a result, reasons for changes, if any, are not fully explained.

The analysis carried out in this study leads to the following conclusions:

- The bus lane has little impact on bus performance during off-peak periods and when traffic is light.
- Prohibition of parking, only at previously congested segments, improves bus performance at those segments.
- Time savings occur at traffic signals (especially at segments accommodating alternative stops) and on previously congested segments.
- Right-turn prohibitions improve bus performance considerably. However, caution should be paid to the adverse impact of diversions of traffic to alternative intersections at which right turns are permitted
- Police enforcement is an important factor in achieving improvements to bus performance, particularly on congested segments.
- The use of reserved lanes by taxis diverted from other streets contribute to bus delays.

- Ridership generally increases after introducing the lane, even without improvements in travel time.

The last finding is noteworthy, since it appears that ridership increased because of the perception of an enhanced service by establishing an exclusive lane, even though total travel time, in one case, increased. In a user attitudinal survey, for example, 91 percent of the respondents expressed positive views of the project and 85 percent claimed they have a reduced transit travel time (*7*).

For future projects the following should be taken into consideration:

- Dedicating curb lanes to bus use during peak periods only;
- Dedicating curb lanes to bus use on a selective basis, at congested segments only, preventing right turns where possible, and revising stop locations, to be alternative at those segments. Police enforcement, however, should be strict at those particular segments;
- Allowing taxis to use the "jumping" lanes (i.e., curb lanes at the segments at which buses are favored) should be considered more carefully because of potential adverse impacts on bus performance; and
- Allowing parking on lightly congested segments.

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Shear Capacity of U-Bolt Connections in Transit Buses

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Laboratory tests were conducted to assess the shear capacity of U-bolt connections used in most transit buses to attach the bus frame and body to the bus chassis. These tests involved the connections in two medium-duty transit buses designed and built in Michigan for the Michigan Department of Transportation. For each test specimen, the shear forces applied and the relative displacements of the components representing the bus frame and chassis were recorded. The results indicated no correlation between the initial U-bolt torque and the shear capacity of the connections, whereas very substantial increases in the rate of load application resulted in slight to moderate decreases in the shear capacity. Increases in the number of U-bolts per specimen from two to three caused slight decreases in average U-bolt shear strength, and substantial increases in the chassis depth caused substantial increases in the U-bolt shear capacity.

A study to assess the structural responses of medium-duty transit buses subjected to various levels of bus deceleration has been conducted at the Department of Civil and Environmental Engineering, Wayne State University. This effort has included parametric studies using finite-element modeling and analysis of typical medium-duty transit buses under various combinations of seat belt usage, passenger seat types, and wheelchair loads (*1,2*). The research also involved laboratory tests that were conducted to assess the shear capacity of the U-bolt connections that are used in most transit buses to attach the bus body and frame to the bus chassis. Similar U-bolt connections are also used in many light utility trucks to attach the truck van or storage compartment to the truck chassis.

The laboratory test results that are presented here involve the bus frame-to-chassis U-bolt connections in two medium-duty transit buses that were designed and built in Michigan for the Michigan Department of Transportation (MDOT). These tests were conducted using a Minnesota Testing Systems (MTS) load frame with a capacity of 2500 kN. For each test specimen, the shear forces applied and the relative displacements of the members representing the bus frame and body versus the bus chassis were monitored and videotaped. Thus, the failure mode or modes for each specimen were determined.

Because the principal goal of the project was to assess the capacity of the U-bolt connections in two existing bus designs, no attempt was made to revise or optimize these original bus designs. Such an optimization study of the bus frame-to-chassis connections would have required a widely expanded scope of work. In addition, no attempt was made to assess the impact of other parameters such as low temperatures, moisture, road salt, and cyclic loading on the shear capacity of the connections. This too would have been far beyond the scope of work for the project.

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LITERATURE REVIEW

A comprehensive literature review conducted as a part of the project showed very little research to experimentally assess the behavior of the structural components or connections of a transit bus (*3*). Reports dealing with front-end crash tests of school and transit buses have demonstrated the potential for slippage of the frame-to-chassis connections. One of the buses used in the UCLA crash tests of transit buses, for example, displaced forward by 430 mm (*4*). Transport Canada reported displacements of up to 610 mm for their school bus tests (*5*). Such large displacements would have probably resulted in the deaths of the bus drivers. Severy et al. stated that "collapsing of the passenger compartment applies violent collision forces directly to the driver and passengers, even when they are adequately restrained" (*4*). Therefore, they recommended that "the bus design should insure that the passenger compartment is securely attached to the frame of the bus by appropriately sized shear bolts at frequent intervals from front to rear along both frame members."

In 1986 Thomas Built Buses crash tested a bus that was specially built with unitized construction that, in crash tests, successfully reduced body displacement to 20 mm (*6–8*). However, it is not clear whether this design change has ever been successfully incorporated into production models of transit or school buses. Moreover, research has not yet been conducted to determine if such changes would harm the safety of the bus passengers because of the increased stiffness of the bus structure and hence the potential for increased levels of deceleration felt by the bus passengers in an emergency. Other than the crash tests just discussed, no other experimental studies have been conducted that were aimed specifically at the shear capacity of the bus frame-to-chassis connections.

BUS DESIGNS TESTED

Tests of the bus frame-to-chassis connections were performed for two medium-duty transit bus designs. These designs were based on specifications developed by MDOT in 1989 and 1992. These buses were manufactured in Michigan for MDOT to be used by smaller cities and rural communities throughout the state. Both the 1989 and 1992 bus designs include models with lengths that vary from 6.4 to 8.8 m and with capacities that vary from 22 to 30 passengers. The typical model for each design has a length of 7.5 m with 13 seats for a capacity of 26 passengers.

All of the steel members in the frame and chassis of these buses are cold-formed steel sections with minimum yield stresses of 207 MPa. Figures 1 and 2 contain longitudinal and transverse cross-section views of the 1989 bus that show the structural components

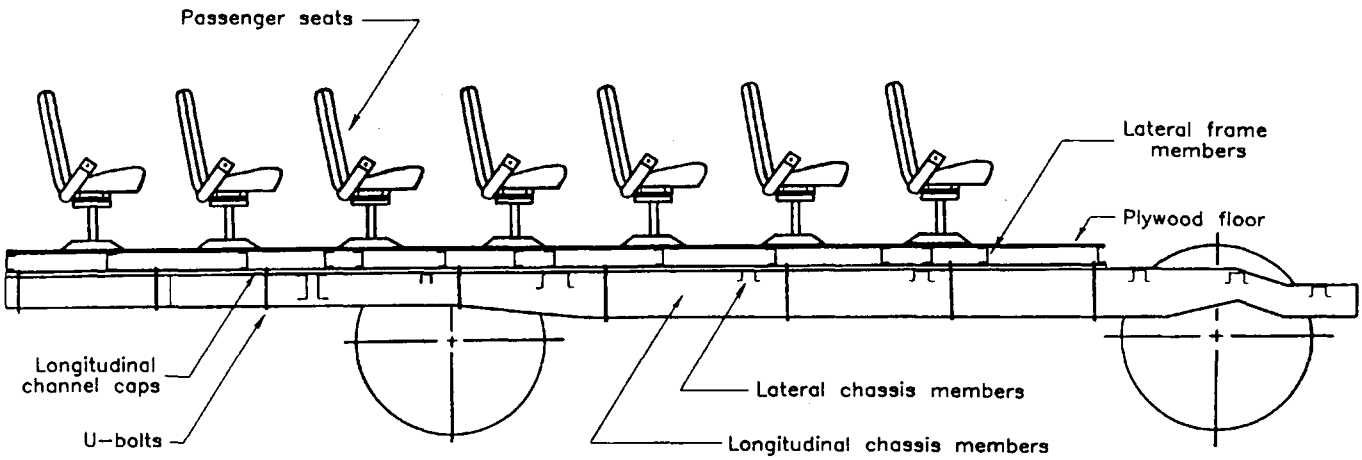

FIGURE 1 Longitudinal cross-section view of bus structure.

of the frame-to-chassis connections. Figures 1 and 2 were first published by Dusseau et al. (*1*). Figure 3 is a cutaway view showing the structural components of the frame-to-chassis connections. The chassis is composed of two longitudinal members that are fabricated from channel sections and are connected at intervals by lateral chassis members. The frame is composed of lateral members that are fabricated from channel sections that run between the bus sidewalls and support the frame (including the skirting and edge members), the floor (including the passenger seats and passengers), and the body (including the doors and windows). The lateral frame members are welded to longitudinal caps that are fabricated from channel sections, that rest on segments of oak filler, and that are attached to the longitudinal chassis members with U-bolt connections and steel shear tabs as shown in Figure 3. The shear tabs are welded along all edges to the longitudinal chassis members and the longitudinal cap members.

TEST SPECIMENS AND PROCEDURES

A schematic diagram of the load frame, test specimen, and connection detail is shown in Figure 4. Each test specimen consisted

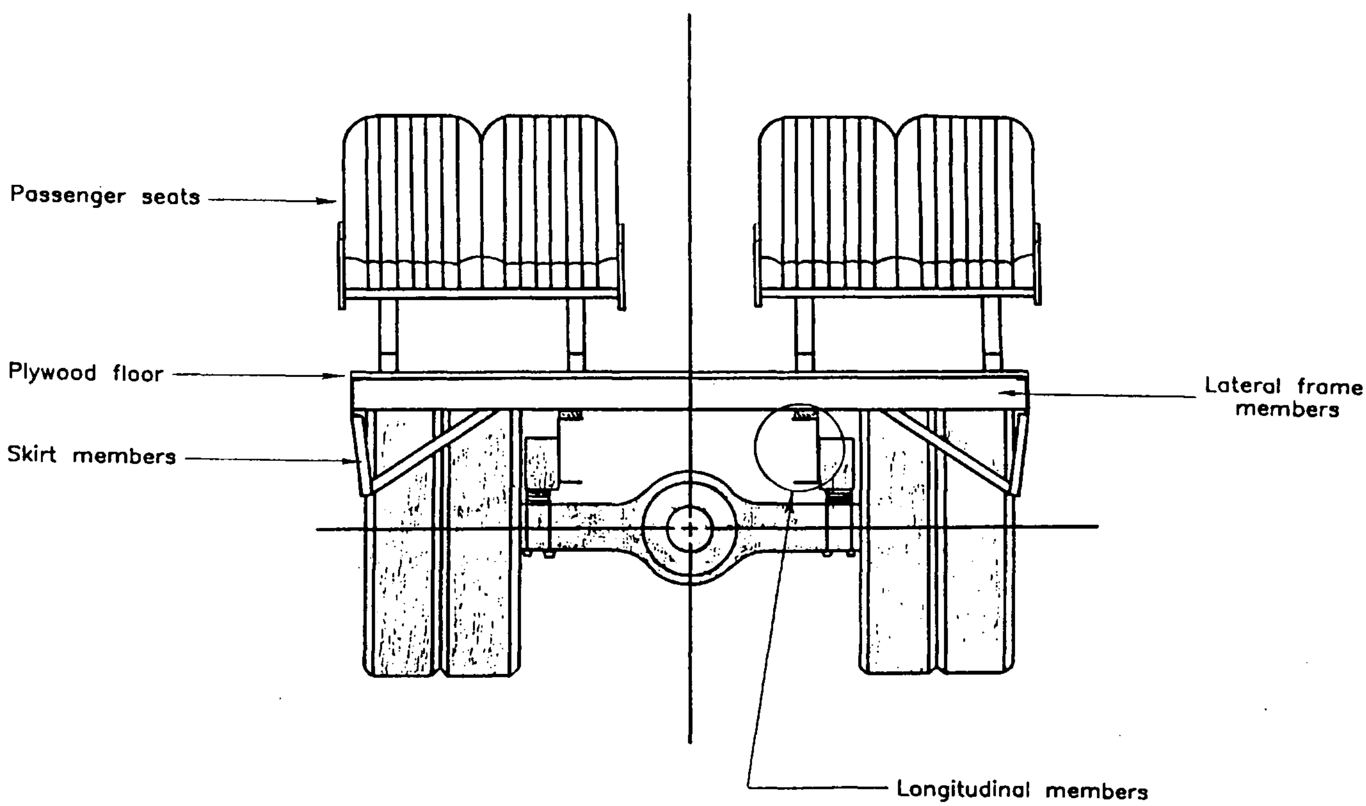

FIGURE 2 Transverse cross-section view of bus structure.

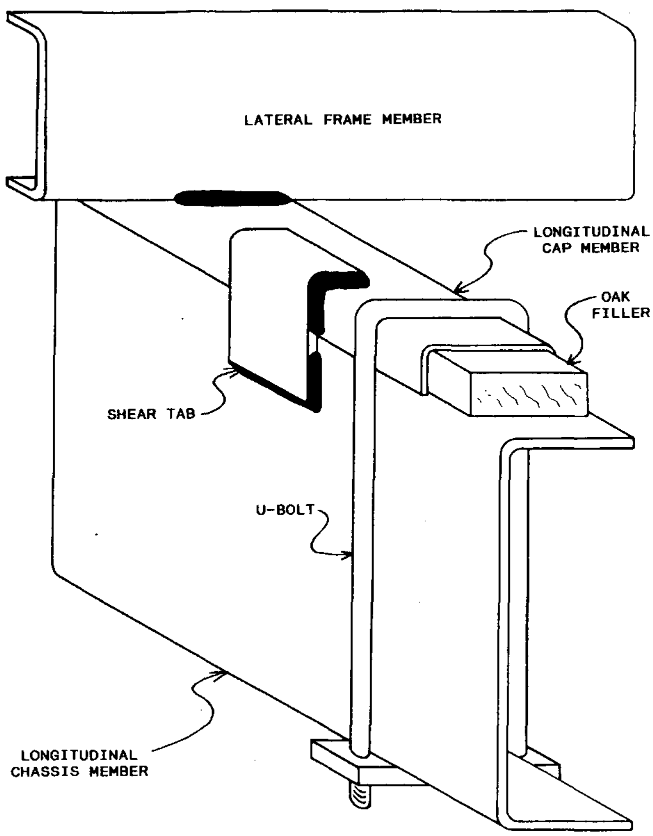

FIGURE 3 Structural components of frame-to-chassis connection.

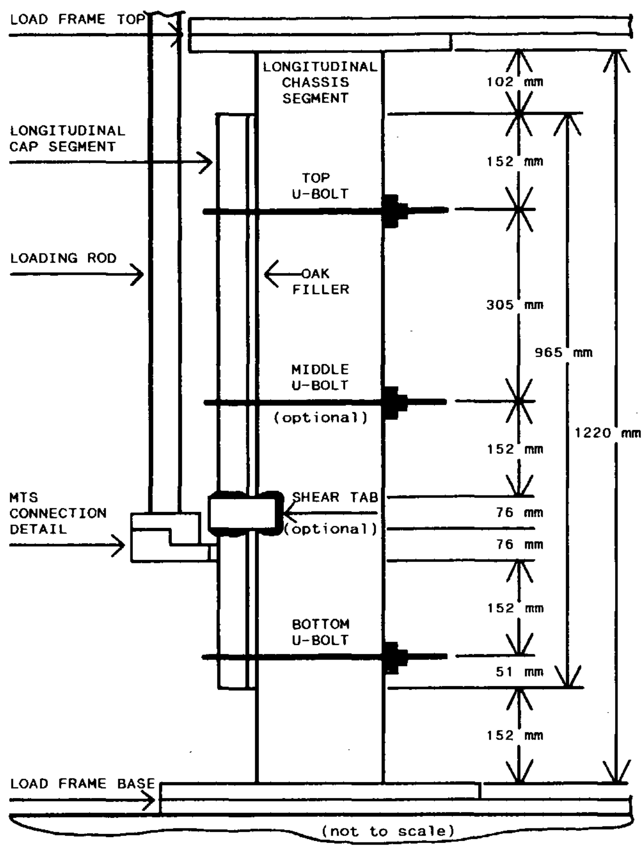

FIGURE 4 Schematic diagram of load platform and specimen.

of the following components:

1. A 1220-mm segment of the longitudinal chassis members that was fabricated from cold-formed steel channel sections with flange widths of 76 mm,
2. A 965-mm segment of the longitudinal cap members that was fabricated from cold-formed steel channel sections with widths of 76 mm and depths of 25 mm,
3. A 965-mm segment of the 64- × 25-mm oak filler that was sandwiched between the longitudinal chassis segment and the longitudinal cap segment,
4. Two or three U-bolts with diameters of 13.3 mm, and
5. An optional steel shear tab with a width of 76 mm.

An MTS connection detail was welded to the longitudinal cap segment and served to connect the test specimen with a 2.5-in. steel loading rod that was fastened to the loading head of the MTS machine. The U-bolts, shear tabs, longitudinal chassis segments, and longitudinal cap segments were all ordered from the same vendors used by the bus manufacturer using the same specifications as the manufacturer.

The principal difference between the test specimens for the 1989 and 1992 buses was the depth of the longitudinal chassis members. These members had minimum depths of 152 mm for the 1989 buses and 229 mm for the 1992 buses. The resulting U-bolts had overall lengths of 203 and 279 mm, respectively.

Shearing forces representing the inertia of the bus body, frame, and passengers that could be generated in an emergency situation were applied to each test specimen through the loading rod and the MTS connection detail and were increased until failure occurred. For each test specimen, the shear forces applied and the relative displacements between the longitudinal cap segment (which represents the bus frame) and the longitudinal chassis segment were recorded. A total of 24 specimens representing the 1989 bus design were tested along with 8 specimens of the 1992 bus design.

1989 BUS DESIGN TESTS

Specimen Configurations

Three parameters were considered in deriving the primary test specimens for the 1989 bus design: U-bolt torque, number of U-bolts, and use of shear tabs. The U-bolt torque used by the bus manufacturer for tightening the nuts on all U-bolts is 74.6 N-m. Because it was initially believed that U-bolt torque could play a role in the shear capacity of the U-bolt connections, six bolt torques were used for the 1989 bus specimens: 61.0, 67.8, 74.6, 81.3, 88.1, and 94.9 N-m. These six U-bolt torques correspond to percentages of 82, 91, 100, 109, 118, 127, and 136, respectively, relative to the manufacturer's U-bolt torque of 74.6 N-m.

Four specimens were tested at each of the six U-bolt torques: two U-bolts with no shear tab, two U-bolts with one shear tab, three U-bolts with no shear tab, and three U-bolts with one shear tab. Thus, 24 primary specimens of the 1989 bus design were tested. For the specimens with two U-bolts, the U-bolt spacing was 761 mm, which is approximately the same as the maximum U-bolt spacing in the 1989 and 1992 bus designs. For the specimens with three U-bolts, the minimum U-bolt spacing of 305 mm is approximately the same as the minimum U-bolt spacing used in the 1989 and 1992 bus designs.

For each test specimen, shear forces were applied using a displacement controls procedure in which the relative displacement of the longitudinal cap segment versus the longitudinal chassis segment was increased at a uniform rate. For the 12 specimens without shear tabs, the rate of relative motion was 25.4 mm/min for the entire 152.4 mm of motion allowed. Although this rate of relative motion is much slower than what might be experienced under emergency conditions, it was initially thought that a faster rate would make it much more difficult to record adequately all of the test results (both measured and videotaped) for the 1989 bus specimens.

For the 12 specimens with shear tabs, the rate of relative motion was 6.4 mm/min for the first 25.4 mm of motion and then 25.4 mm/min for the remaining 127.0 mm of motion. The very slow initial rate was chosen to record adequately the failure mechanism for the shear tabs, which were expected to fail within the first 25.4 mm of relative motion. The rate for the remaining 127.0 mm of relative motion, which was expected to occur after failure of the shear tabs, was the same as the rate used for the 12 specimens without shear tabs.

Test Results

Plots of shear force versus relative displacement were derived for the 24 primary test specimens representing the 1989 bus design. As depicted in Figure 5 for the specimen with a torque of 61 N-m, three U-bolts, and no shear tab, the plots of shear force versus relative displacement for the specimens without shear tabs were all characterized by a gradual buildup of force to a maximum value. This gradual buildup of force began almost immediately as the oak filler started to slip along the top of the longitudinal chassis segment and ended at a relative displacement of 28 to 41 mm when one or more U-bolts slipped (as noted in Figure 5). The U-bolt slippage occurred at the bottom of the U-bolt where the base plate of the U-bolt slid along the bottom flange of the longitudinal chassis segment. For most of these 12 specimens, further cycles of force buildup and slippage occurred, but in none of the specimens did the subsequent shear forces exceed the maximum value derived before slippage of the first U-bolt. The results for all 12 test specimens indicated no apparent correlation between U-bolt torque and shear capacity. This lack of correlation is illustrated in Figure 6, which contains plots of shear force at first U-bolt slippage versus initial U-bolt torque for the four types of specimens that were tested at each U-bolt torque.

As shown in Figure 7 for the specimen with a torque of 61 N-m, three U-bolts, and one shear tab, the plots of shear force versus relative displacement for the specimens with shear tabs were all

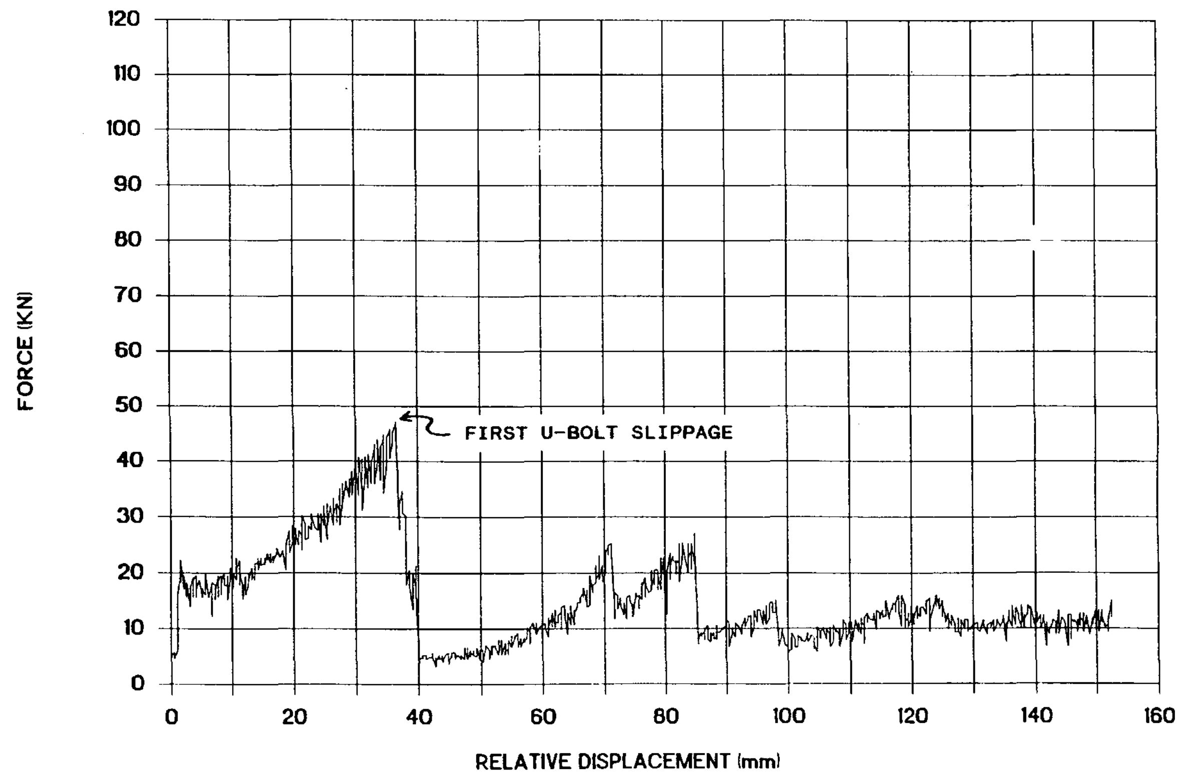

FIGURE 5 Shear force versus relative displacement for 1989 specimen with initial U-bolt torque of 61 kN, three U-bolts, and no shear tab.

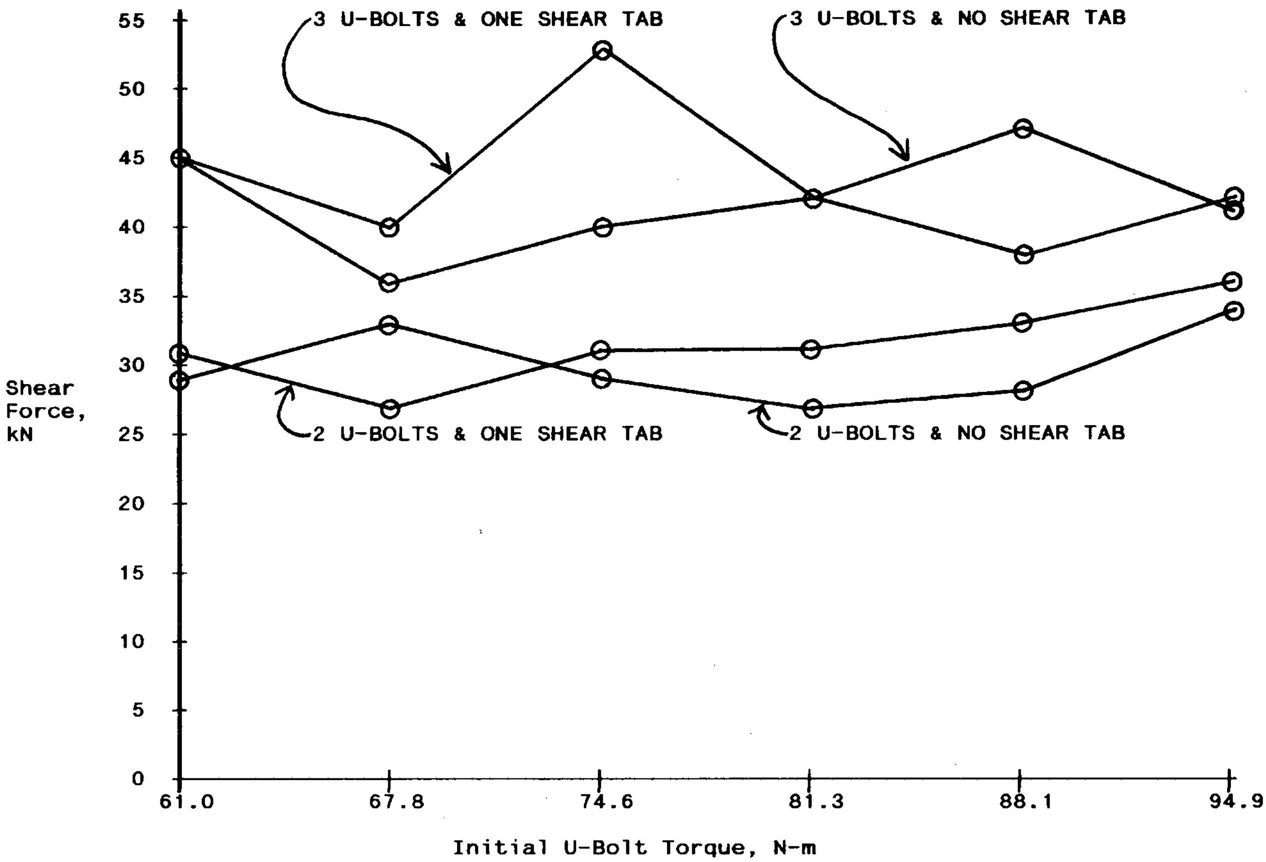

FIGURE 6 Plots of shear force at first U-bolt slippage versus initial U-bolt torque.

characterized by a rapid buildup of force to a maximum value. This rapid buildup of force ended when the shear tabs failed (as noted in Figure 7), which occurred within a relative displacement of 15 mm. The primary mechanism that was observed for shear tab failure was tearing of the shear tab welds. The failure of the shear tabs was followed by a gradual buildup of force similar to the specimens without shear tabs, which ended with slippage of the first U-bolt. The rest of the curves were very similar to curves for the specimens without shear tabs. Because the shear capacity of these specimens was reached when the shear tabs failed, the results for all 12 specimens indicated no correlation between U-bolt torque and shear capacity.

Table 1 presents a summary of the results for the 1989 bus specimens with averages for the four types of specimens tested at each U-bolt torque. The results in Table 1 for each test include the shear force at first U-bolt slippage, the relative motion at first U-bolt slippage, the U-bolt angle of tilt at first U-bolt slippage, and the capacity of the shear tabs for the specimens with shear tabs. Also included in Table 1 are the shear force capacities of the U-bolts and the shear tabs taken as a percentage of the mean values. All but one of the U-bolt shear capacities were within 16 percent of the mean value, and all but one of the shear tab capacities were within 12 percent of the average value.

The average shear capacities for the U-bolts were 15.4 and 14.2 kN/U-bolt for the specimens with two and three U-bolts, respectively. At first U-bolt slippage, the average relative motion was 36.2 mm, and the average U-bolt angle of tilt was 0.176 rad. The first specimen tested with shear tabs (U-bolt torque of 61 N-m and two U-bolts) had a premature weld failure due to the poor quality of this initial weld. Excluding this first specimen, the average capacity of the remaining 11 specimens with shear tabs was about 93.4 kN/tab.

1992 BUS DESIGN TESTS

Specimen Configurations

After testing the 1989 bus specimens and after careful evaluation of the test results, more information was desired on the effects of the rate of relative motion on the maximum shear capacity of the U-bolts and the shear tabs. Thus, the three parameters that were considered for the 1992 bus specimens were rate of relative motion, number of U-bolts, and use of shear tabs. On the basis of the results for the 1989 bus specimens, which indicated that U-bolt torque has no bearing on the maximum shear capacity of the U-bolt connections, the U-bolt torque used for the 1992 bus specimens was the same 74.6 N-m used by the bus manufacturer.

Four specimens of the 1992 bus were tested at the same rates of relative motion as the 1989 bus specimens: two U-bolts with no shear tab, two U-bolts with one shear tab, three U-bolts with no shear tab, and three U-bolts with one shear tab. For the two specimens without shear tabs, a rate of 25.4 mm/min was used for the entire 152.4 mm of motion allowed. For the two specimens

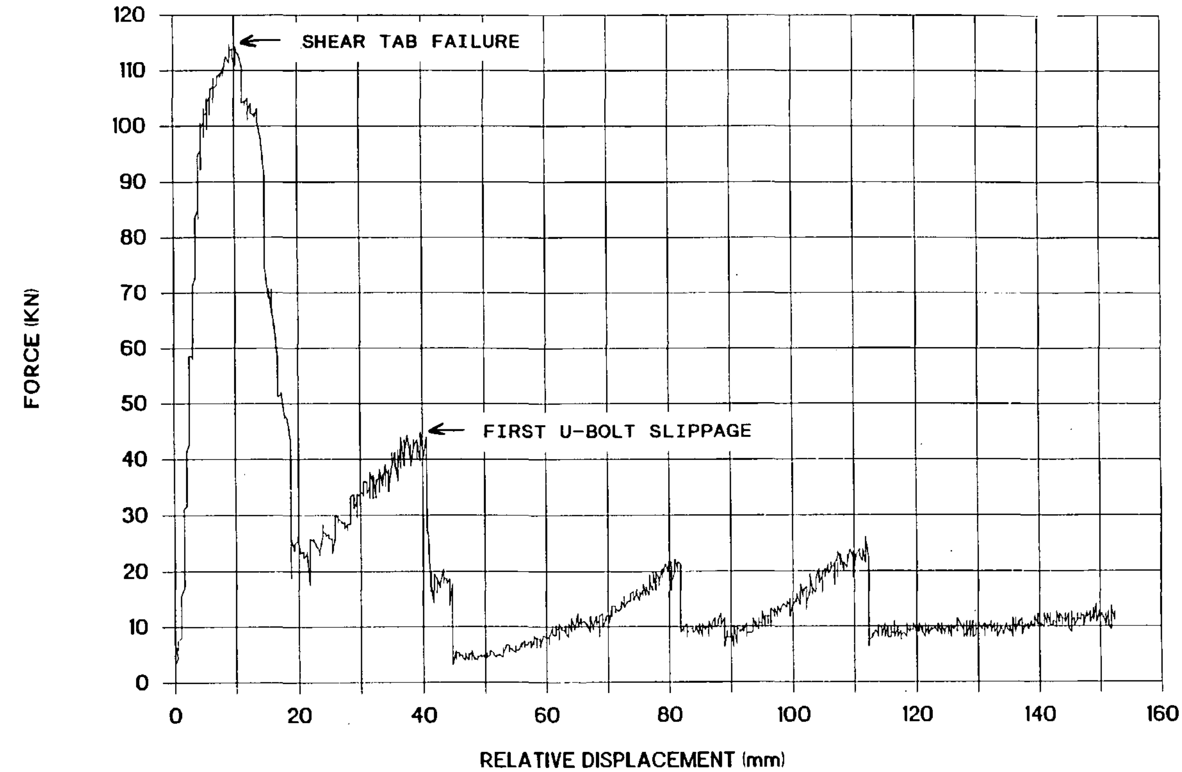

FIGURE 7 Shear force versus relative displacement for 1989 specimen with initial U-bolt torque of 61 kN, three U-bolts, and one shear tab.

with shear tabs, a rate of 6.4 mm/min was used for the first 25.4 mm of motion and a rate of 25.4 mm/min was used for the remaining 127.0 mm of motion.

Four specimens of the 1992 bus were tested at rates of relative motion that were 15 times higher than the rates used for the 1989 bus specimens: two U-bolts with no shear tab, two U-bolts with one shear tab, three U-bolts with no shear tab, and three U-bolts with one shear tab. For the two specimens without shear tabs, a rate of 6.4 mm/sec was used for the entire 152.4 mm of motion allowed. For the two specimens with shear tabs, a rate of 1.6 mm/sec was used for the first 25.4 mm of motion and then a rate of 6.4 mm/sec was used for the remaining 127.0 mm of motion.

Test Results

Plots of shear force versus relative displacement were derived for the eight primary test specimens representing the 1992 bus design. Because of a lack of adequate clearance for certain components of the test specimens, three of the eight primary specimens were stopped short of the 152.4 mm of relative motion originally planned. Despite this limitation, all eight specimens reached at least 105 mm of relative motion, the four test specimens with shear tabs reached shear tab failure, and all eight specimens reached first U-bolt slippage.

As illustrated in Figure 8 for the specimen with the slower rate of relative motion, three U-bolts, and no shear tab, the plots of shear force versus relative displacement for the four specimens without shear tabs were similar to the plots derived for the 1989 bus specimens (Figure 5). As in the 1989 bus results, there was a gradual buildup of force that ended when one or more U-bolts slipped. Unlike the 1989 bus results, however, three of the four 1992 bus specimens reached higher levels of shear force after the first U-bolt slipped. As depicted in Figure 9 for the specimen with the slower rate of relative motion, three U-bolts, and one shear tab, the plots of shear force versus relative displacement for the four specimens with shear tabs were also similar to the plots derived for the 1989 bus specimens (Figure 7). As in the 1989 bus results, there was a rapid buildup of force that ended when the shear tabs failed. This was followed by a gradual buildup of force similar to the specimens without shear tabs, which ended with slippage of the first U-bolt. Unlike the 1989 bus results, however, all four specimens reached higher levels of shear force (due to U-bolt strength) after the shear tabs failed.

Table 2 presents a summary of the results for each 1992 bus specimen with averages for the four types of specimens tested at each rate of relative motion. The results given in Table 2 for each test include the shear force at first U-bolt slippage, the relative motion at first U-bolt slippage, the U-bolt angle of tilt at first U-bolt slippage, and the capacity of the shear tabs for the specimens with shear tabs. Also included in Table 2 are the shear force capacities of the U-bolts and the shear tabs taken as a percentage of the mean values. All of the U-bolt shear capacities were within 18 percent of the mean value, and all of the shear tab capacities were within 11 percent of the average value.

The average shear forces at first U-bolt slippage were 38.3 and 37.1 kN/U-bolt for the specimens with two and three U-bolts, respectively. These much higher U-bolt shear capacities for the 1992 bus specimens versus the 1989 bus specimens were partly the result of steel-to-steel coefficients of friction that were esti-

TABLE 1 Laboratory Test Results: 1989 Bus Specimens

U-bolt Torque, N-m	Number of U-bolts	Shear Tabs? yes or no	Test Results at First U-bolt Slippage: Shear Force, kN	Percent of Mean	Relative Motion, mm	Angle of Tilt, radians	Shear Tab Results: Force, kN	Percent of Mean
61.0	2	no	29	97%	39.8	0.193	NA	NA
		yes	31	100%	36.4	0.177	36*	NA*
	3	no	45	107%	36.9	0.180	NA	NA
		yes	45	105%	41.0	0.199	115	120%
67.8	2	no	33	110%	36.9	0.180	NA	NA
		yes	27	87%	38.4	0.187	98	105%
	3	no	36	86%	36.9	0.180	NA	NA
		yes	40	93%	34.9	0.170	98	102%
74.6	2	no	29	97%	34.9	0.170	NA	NA
		yes	31	100%	38.7	0.188	97	104%
	3	no	40	95%	32.9	0.161	NA	NA
		yes	53	123%	28.6	0.140	95	99%
81.3	2	no	27	90%	37.5	0.182	NA	NA
		yes	31	100%	37.5	0.182	93	100%
	3	no	42	100%	36.4	0.177	NA	NA
		yes	42	98%	36.4	0.177	90	94%
88.1	2	no	28	93%	33.5	0.163	NA	NA
		yes	33	106%	40.4	0.196	82	88%
	3	no	47	112%	38.7	0.188	NA	NA
		yes	38	88%	31.8	0.155	96	100%
94.9	2	no	34	113%	32.3	0.158	NA	NA
		yes	36	116%	39.3	0.191	96	103%
	3	no	41	98%	32.3	0.158	NA	NA
		yes	42	98%	36.4	0.177	85	89%
average test results	2	no	30	100%	35.8	0.174	NA	NA
		yes	31	100%	38.4	0.187	93	100%
	3	no	42	100%	35.7	0.174	NA	NA
		yes	43	100%	34.9	0.170	96	100%

* premature failure, value not included in average test results.

mated to be 55 percent higher for the 1992 bus specimens versus the 1989 bus specimens.

The average relative motion at first U-bolt slippage was 78.2 mm, and the average U-bolt angle of tilt at first U-bolt slippage was 0.273 rad. For the specimens with shear tabs, the average capacity of the shear tabs was 92.0 kN/shear tab.

A comparison of the shear forces at first U-bolt slippage under the fast versus slow rates of relative motion reveals decreases of 5 to 31 percent with an average decrease of approximately 18 percent. Similarly, a comparison of the capacities of the shear tabs under the fast versus slow rates of relative motion reveals decreases of 10 to 19 percent with an average decrease of about 15 percent. Thus, the results for the 1992 bus specimens indicate that a rate of relative motion 15 times faster, which approximates a more severe emergency situation, would result in small to moderate decreases in the shear capacities of the U-bolts and the shear tabs.

CRITICAL BUS DECELERATIONS

The average results from Tables 1 and 2 indicate that the capacity per shear tab should be approximately 93 kN, while the shear capacity per U-bolt should be about 14.8 kN for the 1989 bus design and 37.7 kN for the 1992 bus design. For the 26-passenger (7.5-m) versions of these buses, the number of shear tabs per bus was 2, whereas the number of U-bolts per bus was 14 for the 1989 bus and 12 for the 1992 bus. Thus, the bus shear capacities (F_v) should be approximately 186 kN (2 shear tabs at 93 kN/tab) for the shear tabs in the 1989 and 1992 buses, 207 kN (14 U-bolts at 14.8 kN each) for the U-bolts in the 1989 bus, and 452 kN (12 U-bolts at 37.7 kN each) for the U-bolts in the 1992 bus. Assuming an average passenger weight of about 0.6 kN and assuming the total weight of the bus body, frame, seats, and so forth in the bus passenger compartment to be approximately 10 kN, then the crit-

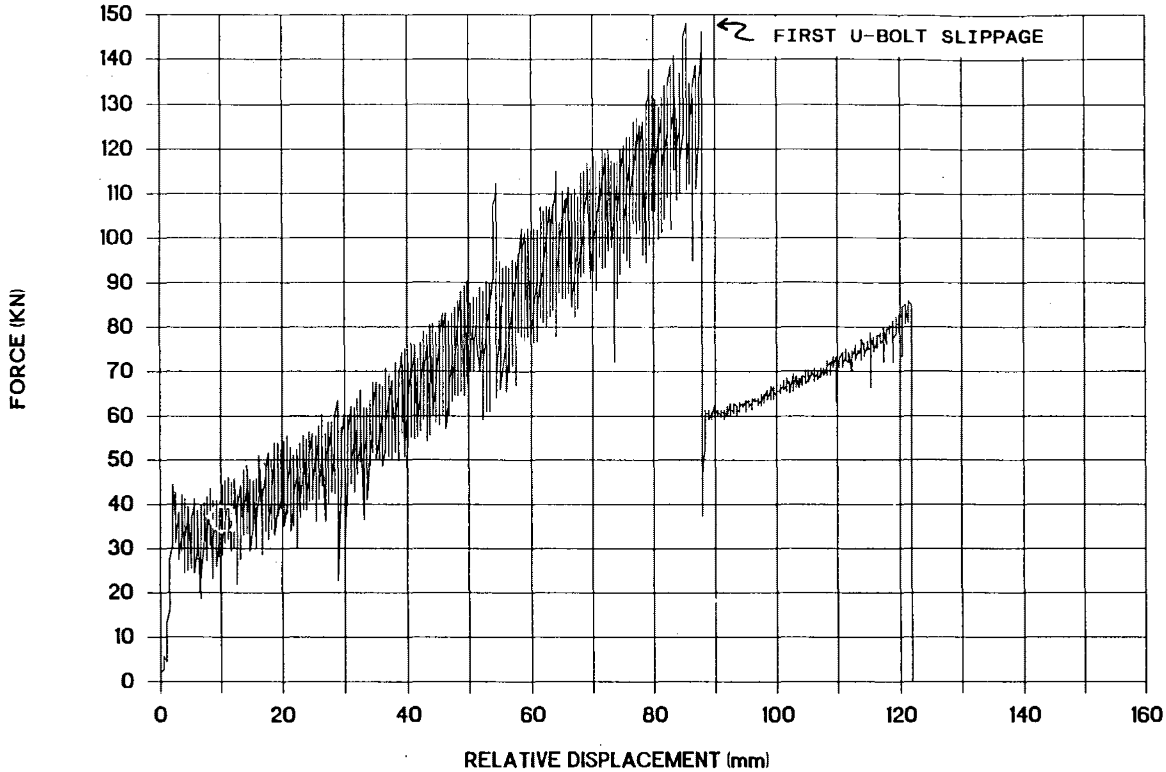

FIGURE 8 Shear force versus relative displacement for 1992 specimen with slow rate of relative motion, three U-Bolts, and no shear tab.

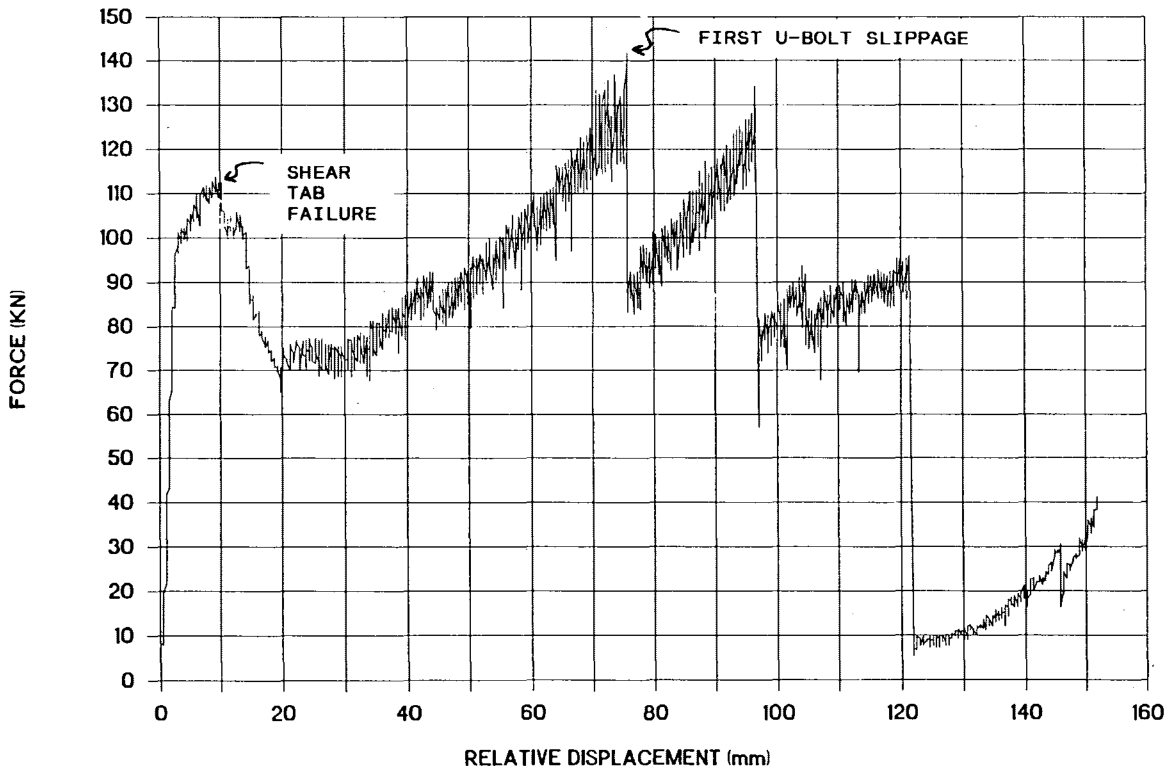

FIGURE 9 Shear force versus relative displacement for 1992 specimen with slow rate of relative motion, three U-bolts, and one shear tab.

TABLE 2 Laboratory Test Results: 1992 Bus Specimens

Rate of Relative Motion	Number of U-bolts	Shear Tabs? yes or no	Test Results at First U-bolt Slippage				Shear Tab Results	
			Shear Force, kN	Percent of Mean	Relative Motion, mm	Angle of Tilt, radians	Force, kN	Percent of Mean
slow	2	no	75	106%	72.1	0.253	NA	NA
		yes	84	102%	84.7	0.294	89	106%
	3	no	129	114%	87.8	0.304	NA	NA
		yes	129	118%	75.6	0.264	111	111%
fast	2	no	67	94%	68.7	0.241	NA	NA
		yes	80	98%	76.2	0.266	80	95%
	3	no	98	87%	88.1	0.305	NA	NA
		yes	89	82%	72.6	0.254	90	90%
average test results	2	no	71	100%	70.4	0.247	NA	NA
		yes	82	100%	80.4	0.280	84	100%
	3	no	113	100%	88.0	0.305	NA	NA
		yes	109	100%	74.1	0.259	100	100%

ical bus decelerations (D_{cr}) required to cause failure of the shear tabs and the U-bolts can be calculated using

$$D_{cr} = \frac{F_v}{[(26) \cdot (0.6) + 10]} = \frac{F_v}{26} \tag{1}$$

where F_v equals the maximum shear capacities of the shear tabs or the U-bolts, in kilonewtons. The resulting critical bus decelerations would be approximately 7 *g* for the shear tabs in both the 1989 and 1992 buses, 8 *g* for the U-bolts in the 1989 bus, and 17 *g* for the U-bolts in the 1992 bus, where *g* is the gravitational acceleration constant (9.81 m/sec^2). Assuming a bus velocity (V) of 25 m/sec, these levels of bus deceleration would translate into stopping distances (L_{st}) calculated as follows:

$$L_{st} = \frac{V^2}{(2 \cdot g \cdot D_{cr})} = \frac{(25)^2}{[2 \cdot (9.8) \cdot D_{cr}]} = \frac{32}{D_{cr}} \tag{2}$$

The resulting stopping distances would be 4.6 m for shear tab failure in the 1989 and 1992 buses, 4.0 m for U-bolt failure in the 1989 bus, and 1.9 m for U-bolt failure in the 1992 bus. These very short stopping distances would most likely require a serious collision involving either a massive stationary object, a vehicle of comparable weight moving at a comparable speed in the opposite direction, or a vehicle of lesser weight moving at a greater speed in the opposite direction. As a comparison, assuming an emergency braking distance without collision of 100 m at a speed of 25 m/sec, the level of bus deceleration required would only be about 0.3 *g*.

CONCLUSIONS

The authors' conclusions relative to the test parameters are as follows:

1. Comparing the 1989 bus specimen results as a function of the initial U-bolt torque, no correlation was found between the U-bolt torque and the shear capacity of the shear tabs or the U-bolts, most likely because the U-bolts yielded before the shear tabs failed and before the first U-bolt slipped.
2. Comparing the 1992 bus specimen results as a function of the rate of relative motion, very substantial increases (+1,400 percent) in the rate of relative motion resulted in slight to moderate decreases (−5 to −31 percent) in the shear capacity of the U-bolts and the shear tabs.
3. Comparing the test results for the 1992 and 1989 bus specimens (with adjustments made for the differences in the estimated steel-to-steel coefficients of friction for each specimen), substantial increases in the depth of the longitudinal channel members (+50 percent) resulted in substantial increases (+65 percent) in the U-bolt shear capacity.
4. Comparing the test results for all specimens, the shear capacities of the U-bolts are somewhat less than 50 percent greater with three versus two U-bolts, which most likely reflects the greater probability of having at least one U-bolt slip if more U-bolts are present. This in turn implies that in the real buses, which have 12 or more U-bolts, the maximum shear capacity before first U-bolt slippage may be somewhat lower than the values derived in the present study.

Conclusions relative to the performance of the typical 1989 and 1992 bus designs are as follows:

1. With two shear tabs each, the typical 1989 and 1992 bus designs would appear to have virtually the same maximum shear tab capacity.
2. After accounting for the differences in the steel-to-steel coefficient of friction for each specimen, the typical 1992 bus design with only 12 U-bolts would appear to have a moderately higher (+41 percent) total U-bolt shear capacity versus the typical 1989 bus design, which has 14 U-bolts.

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Recommendations for Reducing Noncollision Bus Passenger Injuries

JOHN FRUIN, HERMAN F. HUANG, CHARLES V. ZEGEER, AND NORRIS E. SMITH, SR.

Many bus-related injuries do not involve crashes with other vehicles, pedestrians, or fixed objects. These noncollision accidents occur when passengers are riding buses, boarding and alighting buses, and standing or walking at or near bus stops. Data for more than 5,000 bus passenger injuries from the Washington (D.C.) Metropolitan Area Transit Authority were analyzed, which revealed that one-third of all noncollision passenger injuries occurred during boarding and alighting and another one-fourth occurred during stopping. Forty-five percent of the injuries on stopping buses took place as passengers were getting up or sitting down or while they were seated. One-third of the alighting injuries happened when passengers tripped or slipped. The passenger injury rate fell by one-third between 1976 and 1990. A number of measures may be used to improve passenger safety. These measures include interior and seat design to minimize the effects of passenger impact against interior surfaces, far-side bus stops and adequate passenger loading areas, proper bus driver screening and education, appropriate transit agency policies and practices, and organized safety and security reporting.

Crashes and injuries related to buses represent a safety problem on U.S. highways that deserves further study. For example, in 1990 an estimated 64,000 of the 627,000 registered buses nationwide were involved in crashes. As a result of these accidents, approximately 35,000 bus occupants sustained minor or moderate injuries in highway crashes. Another 3,000 sustained serious injury, including 32 deaths (*1*). In addition, each year bus crashes are associated with approximately 100 deaths to nonoccupants (i.e., mostly pedestrians and bicyclists) and 200 deaths to occupants of other vehicles, according to the *Fatal Accident Reporting System* (FARS) (*2*).

Many injuries to bus occupants, however, do not involve crashes with other vehicles, pedestrians, or fixed objects. These "noncollision accidents" may involve trips and falls while passengers are boarding or alighting (e.g., leaving) the bus. While riding the bus, passengers may be injured during sudden stops or movements. These passenger injuries take their toll on passenger safety, yet they are commonly overlooked in transit agency and police accident records. In fact, the major computerized data bases—the General Estimates System, FARS, and the Highway Safety Information System (HSIS)—do not contain information on noncollision accidents. Slightly more than 21,000 personal casualty injuries and 18 deaths were reported to FTA in 1990 (*3*). (Personal casualties are noncollision events that result in injury or death.) Other noncollision accidents are not recorded. Therefore, very little is known about the frequency and severity of these accidents.

This paper reviews the literature on the nature of the injuries sustained by passengers as they ride, board, or exit the bus. It presents analyses of passenger injury data from the Washington (D.C.) Metropolitan Area Transit Authority (WMATA) covering more than 5,000 passenger injuries for July 1984 through January 1991. This paper recommends changes in bus design and bus stop location in order to reduce both collision and noncollision injuries. Recommendations pertaining to driver training and transit agency policies can reduce the number of passenger injuries by reducing the likelihood of a crash.

LITERATURE REVIEW

Bus passengers can be exposed to noncollision accident hazards while riding buses, boarding or alighting the bus, and standing or walking at or near bus stops. Studies of noncollision-related accidents on buses show that most bus passenger injuries are due to falls (*4*).

Analyses of interim data from the National Public Service Vehicle (PSV) Accident Survey showed that about 57 percent of passenger injuries were the result of falls and other incidents that occurred under normal conditions. Another 29 percent of passenger casualties resulted when a bus driver took emergency action to prevent an accident. Only 14 percent of passenger casualties resulted from collisions (Figure 1). In noncollision accidents, 36 percent of the casualties were persons 60 or older, but in collision accidents, only 17 percent were 60 or older (Table 1). For passengers 60 or older, boarding, door entrapment, and gangway accidents accounted for 19, 5, and 27 percent of all noncollision casualties, respectively. The corresponding numbers for passengers under 60 were 11, 2, and 21 percent (*5*). These differences were significant at the 0.01 level.

Cuts, grazes, and bruises to various parts of the body were the most common injuries in noncollision accidents. Cut, grazes, and bruises to the head or neck were more frequently reported from accidents in the gangway (i.e., aisle) and when entering and leaving seats. Leg and foot cuts, bruises, and grazes were more common in doorway and platform accidents. Fractures of all kinds were most often reported for doorway and gangway accidents (*6*).

Passenger falls during the movement of the bus occur because of the forces of sudden acceleration or deceleration, lateral motion on curves, and slip- or trip-related falls. These accidents resulted in 12,103 injuries and 13 fatalities (*3*). Hirshfield found in his famous experiments to develop the President's Conference Com-

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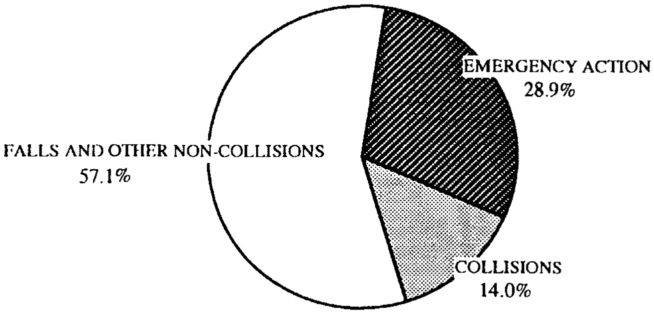

FIGURE 1 Causes of passenger casualties in the National PSV Accident Survey (5).

mittee (PCC) Streetcar design criteria that a 1.47 m/sec^2 (4.83 ft/sec^2, or 0.15 *g*) deceleration or acceleration was the threshold at which people would begin to lose their footing (*7*). Many slips occur on flooring materials that do not have good slip resistance under wet conditions. The presence of foreign materials on the floor, such as spilled beverages or food, also lowers slip resistance.

Boarding and alighting falls occur as a result of slipping or tripping within the stepwell, overstepping the step tread, or falling on the ground surface outside the bus. Accidents while boarding and alighting injured 8,168 persons and killed 3 in 1990 (*3*). Design features such as high steps, inadequate grab handles, and poor illumination of the stepwell contribute to these accidents. Older pedestrians are likely to be overrepresented in boarding and alighting falls, in large part because of their limited mobility and age-related changes in vision, balance, and coordination. Because of the characteristics of stair falls, alighting stepwell falls are typically more serious than boarding falls. In one study of stair falls in transit terminals, 94.1 percent of the ambulance-aided cases occurred in the downward direction (*8*). The reason for this difference in severity is the greater fall height and impact energy of the downward direction stair fall.

Bus stop location, walking surface conditions at the stop, sidewalk width, and illegal parking in bus stop zones are factors that contribute to passenger accidents before boarding or after alighting. In 1990, 842 people were injured and 2 were killed as a result of accidents at bus stops (*3*). Alighting passengers who step onto a rough or icy walking surface may slip and fall. Along a narrow sidewalk, a passenger may be bumped or jostled off the sidewalk into the street or down an abutting slope.

The incidence of noncollision injuries can be reduced by appropriate countermeasures, such as interior vehicle design modifications and by stop locations that passengers can use safely. More information about these countermeasures is provided in the following section.

ANALYSIS RESULTS

WMATA operates one of the largest transit bus fleets in the United States. WMATA supplied summary passenger injury data for 1976 to 1990 and more detailed data for July 1984 to January 1991. The agency also provided summary traffic accident data for 1976 to 1990.

Figure 2 shows that the collision rate (traffic accidents per million miles operated) fell from 73.8 in 1976 to 38.5 in 1986, before rising somewhat in subsequent years (*8*). Reasons for this drop are not known with any certainty. Since 1984 the number of Metrobus traffic accidents has fluctuated around 2,000 per year. The accident types reported involving WMATA buses include vehicles passing on left (26.6 percent), rear-end collisions (14.5 percent), head-on collisions (13.3 percent), angle collisions (9.2 percent), and right-passing vehicles (9.1 percent) (Figure 3). These results show that sideswipe and rear-end collisions prevailed, as was the case with the five-state HSIS data discussed earlier in this paper. For most accident types, the crash percentages by type remained relatively constant from 1976 through 1980 and 1986 through 1990, although accidents involving following vehicles (i.e., vehicles striking the bus from behind) increased from 12.4 to 17.9 percent.

From 1976 through 1990, slightly more than 1,000 accidents occurred involving pedestrians, which was about 2.6 percent of the total number of accidents by WMATA buses. Of the 346 bus-person collisions between January 1984 and January 1991, 72 occurred as the bus was traveling between stops. Fifty-eight pedestrians were struck as buses were leaving stops, 56 were hit in crosswalks, and 160 were struck under other circumstances.

The passenger injury rate (per million passengers) has shown a general downward trend, from 7.3 in 1976 to 4.9 in 1990 (Figure 4) (*9*). Note that the injury rate fluctuated around 7.5 for the years 1976–1982 but then dropped to around 5.0 for 1985 and later years. A possible explanation for this decline would be the replacement of older buses by newer buses with more passenger-friendly interior designs. Roughly a third of all passenger injuries occurred during boarding or alighting, and another fourth occurred during stopping (Figure 5). "Other" and "miscellaneous" accidents combined accounted for another third of the injuries. The percentage share of each passenger injury accident type remained relatively constant from 1976 through 1980 and 1986 through 1990.

TABLE 1 National PSV Accident Survey: Noncollision Casualties by Age (5)

	Estimated Age		
	Under 60	60 or Older	Total
Door entrapment	1.8%	4.6%	3.0%
Boarding	10.9%	19.4%	14.5%
Gangway	20.9%	26.9%	23.5%
Other non-collision	66.4%	49.1%	59.0%
Total	843	635	1478

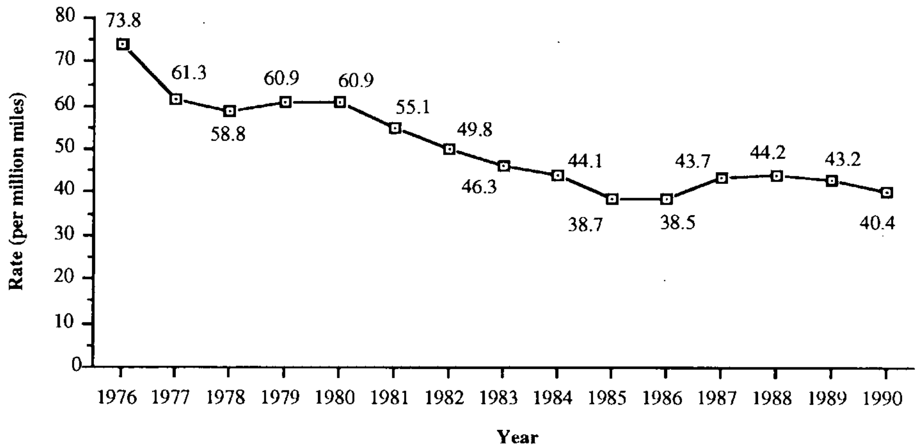

FIGURE 2 Washington (D.C.) Metrobus traffic accident rate by year (*9*).

A more detailed breakdown of 5,507 noncollision accidents that occurred in metropolitan Washington between July 1984 and January 1991 appears in Table 2 (S. Burton, unpublished reports, WMATA, Feb. 1991). Passengers were most likely to be injured while aboard a stopping bus or while boarding and alighting. Forty-five percent of the injuries on stopping buses occurred while passengers were getting up, sitting down, or remaining seated. One-third of the alighting vehicle injuries occurred when passengers tripped, slipped, or stumbled.

The WMATA data do not report injury severity for the traffic accidents and the noncollision passenger injury accidents. Information was not available on potential bus stop safety problems such as far-side versus near-side stop location or adequacy of loading areas.

RECOMMENDATIONS

Several general measures are recommended to reduce the incidence of noncollision passenger injuries. The measures described here may be classified into these categories:

- Bus design and operations to reduce passenger injuries,
- Bus stop location,
- Bus driver screening and education,
- Transit agency policies, and
- Safety and security reporting system.

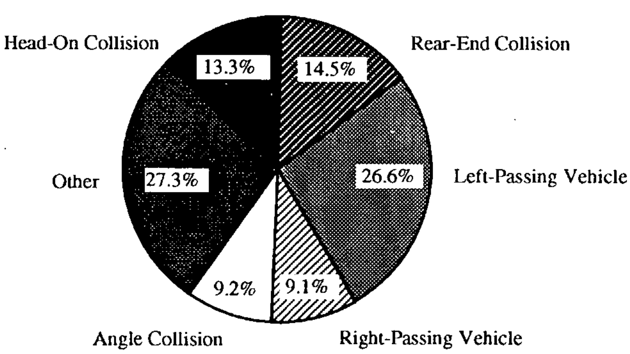

FIGURE 3 Washington (D.C.) Metrobus traffic accidents by type, 1976–1990 (*9*).

Measures relating to bus driver education and transit agency safety policies can eliminate situations in which bus drivers must swerve or stop unexpectedly in order to avoid collisions, thereby injuring passengers.

Bus Design and Operations To Reduce Passenger Injuries

Bus passengers can be exposed to noncollision accident hazards while riding buses, boarding or alighting the bus, and at or near bus stops. Studies of noncollision-related accidents on buses show that most are due to falls (*4*). Passenger falls during the movement of the bus occur due to the forces of sudden acceleration or deceleration, lateral motion on curves, and slip- or trip-related falls. Boarding and alighting accidents are generally related to slips or trips within the stepwell or overstepping of the step trend. Bus stop location, walking surface conditions at the stop, sidewalk width, and illegal parking in bus stop zones are factors that contribute to passenger accidents before boarding or after alighting.

Commercial buses are more likely to be struck by rather than to strike another vehicle, on the basis of the findings from a related study (*10*). Many of these accidents occur when a vehicle rear-ends a bus that has stopped to pick up or discharge passengers. During daylight hours, a stop arm (as is commonly installed on school buses) could be raised to warn drivers who are following the bus that the bus has stopped. Bus conspicuity at night and during inclement weather could be improved through the installation of brighter warning lights on the rear of the bus or perhaps through a special illuminated Stop sign on the rear of the bus.

Some rear-end and sideswipe accidents may be prevented by improving the visibility of turn signals on buses. Audible warning devices could be attached to buses to warn other motorists of the presence of a bus. Even closed-circuit television cameras could be installed to give the bus driver a better view of the sides and rear. To reduce injury severity to the driver and occupants of the other vehicle, energy-absorbing material may be placed at the front and the back of the bus.

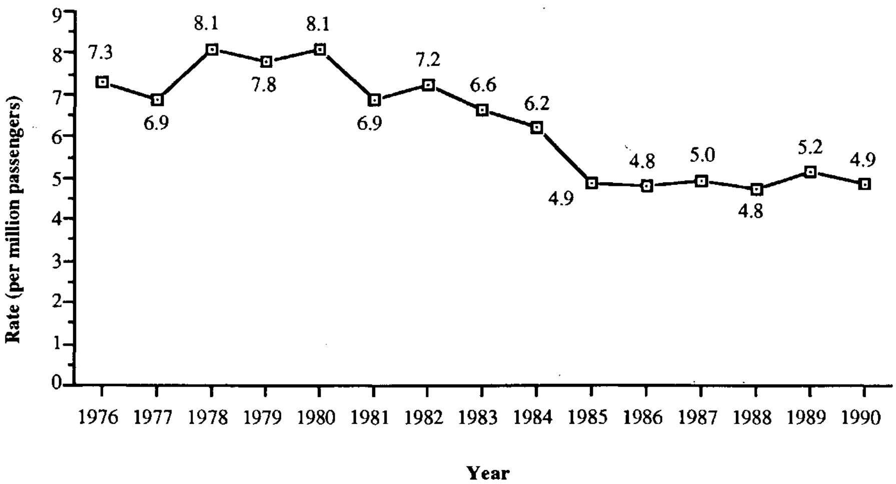

FIGURE 4 Washington (D.C.) Metrobus passenger injury rate by year (9).

Motion-Related Falls

Sudden deceleration of buses is unavoidable when the driver must stop to avoid a vehicular accident or obey a changing traffic signal. Ideally, buses should not operate with standees in the aisles, but this objective is difficult to attain. Where seats are available, every effort should be made to encourage passengers to sit while the bus is in motion and to remain seated until the bus stops. The strategic location of handholds, within easy reach of passengers in aisles, is another means of preventing motion falls. Excessive forces due to acceleration and lateral movement on curves can largely be avoided by training drivers to be aware of passenger motion hazards.

In both motion- and collision-related falls, the effects of second impacts should be minimized (5). These impacts occur when passengers are thrown about the interior of the vehicle. All interior surfaces, edges, trim, and such should be designed so that clothing will not be caught and the victim will not be cut by sharp edges. Interior seats, partitions, railings, and other elements should be securely mounted so that they will not loosen during normal use or under the force of a collision. Protrusions that passengers can bump into under normal use or during falls should be avoided wherever possible. The use of materials that shatter or break upon impact should also be avoided. Padded surfaces give passengers added impact protection in a collision but are also known to encourage vandalism.

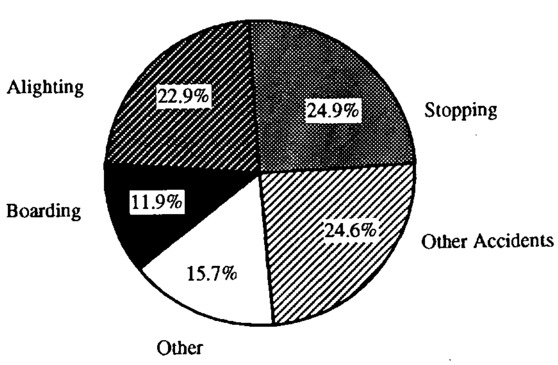

FIGURE 5 Washington (D.C.) Metrobus passenger injuries by type (9).

Falls Due to Trips and Slips

The selection of non-slip flooring material, careful application of these materials, and continued maintenance of a safe walking surface is necessary to reduce slipping and tripping falls in buses. The standard for a slip-resistant walking surface is set by the U. S. Architectural and Transportation Barriers Compliance Board (USATBC) (*11*). Many flooring materials that are normally considered slip-resistant will not meet that standard. Flooring materials selected for bus transit use should be tested for slip resistance using procedures specified by ASTM or their recognized equivalents (ASTM C1028-89, ASTM D2047-82). Slips on bus floors can also result from newspapers, spilled foods or liquids, mud, and other foreign materials on the floor. Slip accidents in northern climates can occur because of icing of stepwell treads.

Tripping hazards occur where the walking surface is not level. In the normal walking pattern toe clearances vary between 0.95 and 3.81 cm (0.375 and 1.5 in.), with an average of about 1.52 cm (0.6 in.) (*12*). However, passengers in buses, particularly those standing in aisles, could trip on surface differentials lower than 0.95 cm (0.375 in.) in a lateral or sideways movement of their feet as they adjust standing positions. The USATBC has set a standard of a surface height differential of 0.64 cm (0.25 in.) as the threshold at which trip hazard mitigation should occur (*13*). Tripping hazards do not generally occur with bus floor surfaces unless the surface is worn or the surface materials become loose or dislodged in some manner. This requires periodic inspection of bus floors and replacement of floors with tripping hazard defects. To avoid slipping hazards caused by spills or refuse, the consumption of food and drink should be prohibited on buses.

Boarding and Alighting Falls

Boarding and alighting falls occur within the stepwell or on the ground surface outside the bus. Because of the characteristics of

TABLE 2 Washington (D.C.) Metrobus Noncollision Accident Types, July 1984–January 1991

Passenger injury boarding vehicle	681 (100%)
- Struck by front doors closing	34.9%
- Tripped, slipped, stumbled	32.9%
- General	9.0%
- Between street and step at front door	7.8%
- Other	15.4%
Passenger injury alighting vehicle	1215 (100%)
- Tripped, slipped, stumbled	33.2%
- General	15.7%
- Struck by center/rear doors closing	13.7%
- Between street and step at front door	9.9%
- Struck by front doors closing	7.5%
- Other	20.0%
Passenger injury on board starting bus	142 (100%)
- Walking front seat area	23.2%
- Standing front door area	19.7%
- Other	57.0%
Passenger injury on board stopping bus	1508 (100%)
- Getting up/down/seated	45.4%
- General	16.6%
- Standing front door area	10.3%
- Standing front seat area	7.2%
- Walking front seat area	7.1%
- Standing rear seat area	5.6%
- Walking rear seat area	4.3%
- Other	3.4%
Passenger injury on board moving bus	382 (100%)
- Getting up/down/seated	54.7%
- General	10.2%
- Standing front door area	9.9%
- Other	25.1%
Other passenger injury	1200 (100%)
- Injured by defective equipment while on board	24.0%
- Injured by missile while on board	19.4%
- General	17.1%
- Bus standing: trip, slip, or stumble	13.4%
- Injured by others on board	11.0%
- Bus moving: tripped, slipped, stumbled	7.8%
- Other	7.3%

stair falls, alighting stepwell falls are typically more serious than boarding falls. In one study of stair falls in transit terminals, 94.1 percent of the ambulance-aided cases occurred in the downward direction (*8*). This difference in severity is caused by the greater fall height and impact energy of the downward-direction stair fall. The elements of safe stair design are well established (*14–16*). Riser heights should be between 15.24 and 20.32 cm (6 and 8 in.) and effective tread width between 27.94 and 30.48 cm (11 and 12 in.). A well-established safety requirement is that riser heights and tread widths be consistent and equal within small tolerances in any stair flight. Handrails should be reachable and graspable and should extend beyond the top and bottom treads. Treads should be well lighted, and step edges visually well defined. Tread surfaces should be slip-resistant.

The kneeling bus was developed to reduce the height from the ground to the first step on the bus for the convenience and safety of users. Many drivers dislike using the kneeling mechanism, and it can lock in the kneeling position or otherwise malfunction, sometimes taking the bus out of service.

The low-floor bus was developed recently to overcome stepwell safety problems and to provide a simpler means of accommodating wheelchair users (*17*). The bus floor in one manufacturer's version is 36.53 cm (14.38 in.) above ground, and the ground clearance under the rear axle is only 15.24 cm (6 in.). This manufacturer also offers a kneeling mechanism option to lower the bus floor another 3 to 4 in. Wheelchair access is by way of a ramp. The bus is being tested at a major regional airport. It is claimed that the low floor is speeding up the loading and unloading of passengers with baggage, greatly reducing dwell and turnaround times.

The Americans with Disabilities Act (ADA) Subpart D, Section 37.71, entitled "Purchase or lease of new non-rail vehicles by public entities operating fixed route systems" paragraph (a), states that

> [e]xcept as provided elsewhere in this section, each public entity operating a fixed route system making a solicitation after August 25, 1990, to purchase or lease a new bus or other new vehicle for use on the system, shall ensure the vehicle is readily accessible and usable by individuals with disabilities, including individuals who use wheelchairs. (*18*)

There are few waivers to this requirement, ensuring that with the normal replacement of existing bus fleets, eventually all public buses will be accessible to wheelchairs.

Seat Design and Performance

Good seat design is an important countermeasure to reduce passenger injury either as a result of collisions or of sudden stops by the bus. Past accident studies have shown that many passenger injuries result from a lack of seat retention or from the impact of unrestrained seats with otherwise uninjured occupants.

Among designers, legislators, and researchers, it is generally agreed that seat performance should achieve two major objectives:

- In the event that a passenger impacts the seat in front, the seat should be capable of local deformation in the knee and chest area to enable "pocketing" of the passenger, thus absorbing some of the initial kinetic energy. It should also provide for controlled deformation of the seat back (without fracture) to absorb the remaining kinetic energy and prevent the passenger from ramping over the top of the seat.
- Through careful design and placement of structural members and the use of adequate energy-absorbing padding, the seat should be capable of distributing local impact forces to the head, thorax, chest, and knee areas in such a way as to prevent serious injury (*19*).

A seat should be designed with

- Strong seat anchorages to ensure seat retention,
- Provision for knee penetration to minimize femur forces and to prevent the pivoting of the upper body and consequent high head impact loads,
- Adequate seat back height to prevent ramping and unacceptable head impact.
- Suitable seat and back stiffness to allow passenger retention without premature seat collapse or excessive body forces,
- Adequate energy-absorbing padding in the knee and head protection zones to prevent unduly high localized forces, and
- Suitable seat-back angle to enhance the retention capabilities of the seat (*19*).

Bus Stop Location

The safety responsibility of bus transit carriers has been extended to bus stop loading and unloading areas under some circumstances. For example, boarding and alighting passengers may slip and fall on icy surfaces. They may be bumped off narrow sidewalk loading areas, perhaps into the street or down an embankment. In rural or suburban areas, passengers may be unloaded at unpaved areas where there is greater bus-to-road step height, poor footing, or tripping hazards.

Transit agencies should provide adequate loading areas for passengers, reasonably free from safety hazards. This responsibility will increase as ADA accessibility and facility design requirements become the common standard of practice. Bus stops should be located in paved areas with slip-resistant walking surfaces and should be free from tripping hazards. The criteria for slip resistance and tripping hazard height are outlined in American National Standard ANSI-A117.1. The stop area should be wide enough to allow for queueing passengers and to accommodate wheelchair loading and unloading without disrupting normal on-street pedestrian movement near the stop. Passengers in a single-file queue typically line up with an interpersonal spacing of 0.508 m (20 in.) and require a lateral space of 0.762 m (30 in.) (*20*).

Near-side versus far-side bus stop location has an impact on passenger and pedestrian safety (*21,22*). Factors that influence the selection of bus stop locations include the availability of curb and sidewalk space, bus routing patterns (turns), location of other stops or bus services, passenger and street pedestrian volumes, passenger accessibility, street width, one-way or two-way streets, traffic volumes and turning volumes, traffic controls, and signal cycles. From the viewpoint of bus passenger and pedestrian safety, the far-side location is the safest because pedestrians cross in the crosswalk behind the bus where they can be seen and because the bus does not block the view of traffic controls and other intersection traffic. Other advantages of the far-side bus stop include

- Reduced bus conflicts with right-turn vehicles,
- Increased intersection capacity by freeing the curb lane for through movement,
- Improved sight distances at intersections,
- Shorter curb length requirements for bus stop approaches, and
- Easier reentry into traffic after passenger loading.

Bus shelters protect passengers from wind, rain, and snow. Shelter location is an important consideration because the shelter can occupy sidewalk area needed for passenger waiting, boarding and unloading, and other nearby pedestrian activities. If the shelter is located too close to the curb, the restricted space between the fixed shelter and the moving bus can become hazardous to passengers.

Bus Driver Screening and Education

To the best of the authors' knowledge, there has not been any research that measures the effects of bus driver training on the number of collision and noncollision accidents. The National Transportation Safety Board investigates selected bus accidents to determine their causes and to recommend countermeasures. For some accidents, the safety board has recommended that bus companies review and modify the driver training process as a countermeasure after determining that the drivers' actions were the probable causes of those crashes (*23*).

Recommendations for improved bus safety as affected by the bus driver have been developed by the Wisconsin Department of

Transportation and other sources (*24,25*). They include the following:

1. Thoroughly screen potential bus drivers. The screening process should consider the applicant's past driving record and include a physical examination, a drug test, and a background check.
2. Properly train newly hired drivers, covering both standard and emergency operating procedures. Driver training should consist of four stages: classroom training, off-the-road vehicle training, road work and route familiarization, and revenue service under observation.
3. Develop a structured recurrent training program. Such a program should include classroom instruction as well as simulator or behind-the-wheel instruction. The program should be geared toward maintaining and reinforcing good driving habits. Additionally, remedial training should be developed for and given to "problem" drivers.
4. Continually monitor and evaluate the performance of drivers. This assessment should be done by someone who is familiar with the driver's record, qualified to interpret it, and authorized to impose appropriate measures such as remedial training or disciplinary action.

Transit Agency Policies

A number of policies and practices by transit agencies can help to minimize risk of collisions and passenger injuries related to transit bus operations. These include (*24*)

1. Routing should lower accident exposure by minimizing turns, allowing for intersection controls, avoiding dangerous intersections, and not crossing several lanes of traffic. Schedules should incorporate adequate running time so that drivers do not feel compelled to speed. Transit bus schedules should also include layover time to give drivers a short break and to allow for traffic delays.
2. Inspect and maintain the bus regularly. Effective preventive maintenance not only makes buses safer, but also adds to their useful life and reliability. Daily inspections are needed to check fuel tank and other fluid levels, replace burned out lights, and so on. Pretrip inspections should include vehicle systems, access doors, and the bus interior. Periodic inspection should be made to detect damage before major repairs are necessary.

Inspection and maintenance are especially important for older buses, since the analysis showed that older buses are overrepresented in crashes (*26*).

Ideally, specific departments or individuals within transit agencies should be assigned responsibility and authority for implementing, performing, and monitoring various safety activities. These activities should include equipment and facility inspections, safety instruction, monitoring of employee work habits, incentives, accident reporting and investigation, meetings, and program documentation. A safe driver award program, based on the number of days without a collision or on-board accident, can offer a strong incentive for drivers to operate their buses more safely.

Safety and Security Reporting System

An organized safety and security reporting program is important for bus transit carriers to monitor the number and types of incidents occurring in the system (*27*). Buses should be equipped with two-way radios so that the dispatcher can be notified when an accident has occurred. To facilitate accident investigation, a report needs to be completed for each accident and a supervisor should be dispatched to the scene. These data can provide useful insights on the potential causes of these incidents and help to identify appropriate preventative measures. A thorough record of an incident can prove to be invaluable if there is a subsequent litigation related to it. At times, facts can be altered where there is no record or the record is incomplete.

Future Research Needs

One area of needed research would involve a more extensive data base, to be obtained from local transit agencies, of noncollision accidents. These data would allow better comparisons of different bus designs and operating practices. More information is needed on how bus design affects passenger injuries. Buses are manufactured to varying specifications pertaining to seat type, floor material and aisle width, handrail placement in stairwells, step height, and other design features. Different models should be tested to identify those whose specifications minimize boarding and alighting falls, motion-related falls, and the likelihood of injuries.

Buses should be subjected to crashworthiness tests to determine the level of driver and passenger safety offered by various bus designs. Computer simulation of bus crashes could also be attempted. Accident reconstruction studies of bus crashes could help to identify specific crash causes.

Research is also needed on accidents in which the bus contributed to an accident but did not collide with other vehicles or persons. For example, pedestrians may step in front of buses and be struck by passing automobiles. However, for such accidents bus involvement would not have been coded in the data base. It would probably be very labor intensive to collect adequate data samples in these two areas, but the results would probably be useful for transit agencies.

Research should be undertaken to quantify the characteristics of bus stop accidents, such as boarding and alighting riders who trip on slippery or uneven surfaces at stops, waiting riders who are forced to stand out in the street because of an inadequate waiting area and are thus struck by an approaching bus or other vehicle, and alighting riders who are struck by motor vehicles while trying to cross the street in front of the bus. Data would be readily available if transit agencies adopted a safety and security incident reporting system.

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Public Bus Accident Characteristics in Ohio

LI-YEN CHANG AND RAMEY O. ROGNESS

Characteristics of public bus accidents in Ohio from 1989 to 1991 are identified. Analyses were conducted for determining accident characteristics of the six Ohio major transit systems; this included comparing the average bus accident rates and comparing the average bus accident rates under various conditions for each major transit system. The comprehensive results indicate that Southwest Ohio RTA (Cincinnati) had the highest bus accident rate and that Greater Cleveland Regional Transit Authority (RTA) (Cleveland) and Miami Valley RTA (Dayton) had the lowest bus accident rates. Central Ohio Transit Authority (Columbus), Toledo Area RTA (Toledo), and Akron Metro RTA (Akron) had similar bus accident rates. Rain is found to be a contributing factor to bus accident occurrence, especially for those transit systems in the northern part of Ohio. Snow and clear conditions for weather or roadway conditions were not different in terms of accident occurrence for the systems.

Safety is an important attribute of public transportation for both the operators and the passengers. For the operator, accidents will cause additional costs, lost time, and out-of-service time. A safe public transit system may be a factor to encourage public use.

OHIO PUBLIC TRANSIT SYSTEMS

Fifty-eight public transit systems that offer fixed-route and demand-responsive service are operated or sponsored by local public agencies in Ohio. The Ohio transit systems can be classified into metropolitan systems with regional transit authorities (RTAs) in the larger areas, small urban systems, and rural systems based on annual ridership and service area population (*1*).

Metropolitan Systems

Eight major transit authorities serve the metropolitan areas with over 1 million annual public transportation riders. Greater Cleveland RTA, Southwest Ohio RTA, Central Ohio Transit Authority (COTA), Miami Valley RTA, and Toledo Area RTA are the five largest transit systems in Ohio. Annual ridership of each system exceeds 10 million and ranges to more than 70 million. Large bus fleet ranging from 250 to 740 vehicles are a particular characteristic of the major transit systems. The five large and three medium systems serve three-fourths of the state's population and contain 89 percent of Ohio's transit bus fleet as well as 95 percent of public transit ridership.

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Small Urban and Rural Systems

More than half of the public transit systems in Ohio serve small cities or villages or rural areas. Small buses make up about a half the vehicle fleet, and the remainder is composed of vans and other vehicles.

LITERATURE REVIEW

Only a few studies have been reported on public bus accidents. The analysis methods and related findings of these studies are summarized as follows.

One of the most comprehensive of the transit bus accident studies was done by Jovanis et al. in 1989 (*2*). They analyzed about 1,800 mass transit bus accidents that occurred in the Chicago metropolitan area and developed two regression models for measuring transit accidents. The accident data were provided by PACE, the suburban bus agency. The important findings are summarized as follows:

- Eighty-nine percent of the accidents involved collision with another object or person, and the remaining 11 percent involved passenger injuries while boarding, alighting, or moving.
- Severity was generally low; most accidents involved property damage only.
- Drivers of the other vehicle involved in the accident were much more likely to be injured than the bus drivers.
- Gender does not contribute to accident occurrence, but age appears to have an effect on accident involvement.
- Seventy percent of the collision accidents occurred at intersections, whereas 30 percent occurred at some other locations.
- Bus accidents do not appear to be more frequent during darkness.

A study by Jovanis and Delleur in 1983 looked at exposure to accident risk, including characteristics of the amount of travel, conditions of travel, and characteristics of the driver and vehicle undertaking the travel (*3*). A series of paired comparisons of accident rates between trucks and automobiles on the Indiana Tollway under different weather conditions of travel and regression analyses were conducted to study the relationship between variables, particularly the influence of one mode's vehicle miles of travel (VMT) on the other's accident rate (i.e., interference between modes) and effect of the amount of snow, rain, and nighttime travel on accident experience. The results from the regression analyses indicated that the occurrence of snow was the single most significant exposure variable and that automobile accident rates were found to increase significantly with truck VMT.

TABLE 1 Six Ohio Major Transit Systems (1)

Name	Service area	No. of vehicles	Route	Annual Ridership (1,000)	Employees
Toledo Area RTA	Toledo	227 buses	36 bus	10,567.8	346
Greater Cleveland RTA	Cleveland	788 buses 94 hvy rail 67 lt rail	98 bus 1 hvy rail 2 lt rail	75,206.8	2,582
Akron Metro RTA	Akron	113 buses	28 bus	5,133.5	263
COTA	Columbus	336 buses	53 bus	20,456.5	672
Miami Valley RTA	Dayton	227 buses	28 bus	15,244.8	466
Southwest Ohio RTA	Cincinnati	380 buses	44 bus	27,566.7	888

Herd et al. studied accidents during daylight and darkness on the urban and rural roads in 1980 using accident data from Louisville, Kentucky (4). The results showed that accident rates on all types of rural roads were higher during darkness than during daylight.

However, no study has been undertaken on the subject of exposure analysis of bus accidents. This study, based on Ohio accident data, focuses on a thorough examination of aggregate bus accident data and the development of a set of hypotheses concerning accident causality. Then statistical procedures are used to identify the factors contributing to bus accidents.

The objectives of this study are to

1. Identify specific problems and characteristics of bus accidents in terms of safety-related variables, such as weather condition, light condition, and pavement condition;
2. Evaluate the safety performance of six major transit systems in Ohio; and
3. Identify whether or not weather has an impact on bus accidents in Ohio.

Toledo Area RTA, Greater Cleveland RTA, Akron Metro RTA, COTA, Miami Valley RTA, and Southwest Ohio RTA are the six largest transit systems in Ohio. All of these systems have annual riderships of more than 5 million; Greater Cleveland has up to 75 million riders each year. In order to have a large enough pool of accident data and still have a manageable set of data to isolate variables and factors, it was decided to concentrate on the accident records of these largest six transit systems instead of using statewide bus accident data to compare the bus accident rates. Doing this gave a wider geographical spread and similar operating characteristics.

The other reason to choose these six systems is the vehicle fleet operated by Ohio transit systems. Most transit systems (except these six systems) operate both buses and vans. Therefore, choosing the six major transit systems enables one to focus on the bus accidents only. Table 1 presents the basic operating characteristics of these six systems, and Figure 1 shows their locations.

All analyses carried out are based on statistical analysis and significant results. The methodology to be used in this study is as follows:

1. Use a single-factor analysis of variance (ANOVA) to test whether there is any significant difference among the mean accident rates of the six major transit systems. If this test concludes that at least two of these means are different, then the Bonferroni multiple comparisons procedure is followed to compare the significant differences between each paired mean accident rate.
2. Use a single-factor ANOVA to test whether there is any significant difference among the mean accident rates in various weather conditions for the six major transit systems. If this test concludes that at least two of these rates are different, then the Bonferroni procedure is followed to determine in what weather condition the transit bus system has a higher accident rate.

DATA COLLECTION AND CODING

To carry out this study, two types of data are needed: transit bus accident data, and exposure data (i.e., VMT). Climatological data were also required for creating exposure measures for bus accident occurrences in different weather conditions.

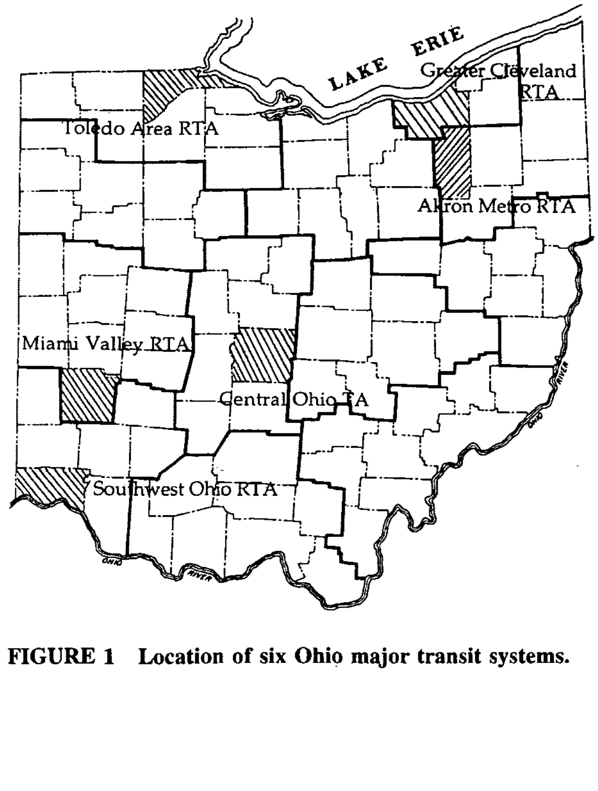

FIGURE 1 Location of six Ohio major transit systems.

TABLE 2 Number of Accidents Involving Buses, Systems and State

Year	Toledo	Cleveland	Akron	Columbus	Dayton	Cincinnati	State
1989	154	315	74	187	86	265	1270
1990	146	341	70	195	84	301	1326
1991	127	286	73	201	88	304	1279

Transit Accident Data Collection

The transit bus accident data came from the Traffic Accident Record System and were supplied by the Ohio Department of Public Safety (ODPS) for 1989 to 1991. The coded information for each accident contains 141 variables, including jurisdiction of roadway, county, and route number. Some variables analyzed in this study are month of accident, day of accident, year of accident, day of week, hour of day, light condition, vehicle type of Vehicle 1, vehicle type of Vehicle 2, vehicle type of Vehicle 3, weather condition, roadway condition, location of accident, type of accident (first harmful event), and accident severity. Transit-bus-related accidents are easily identified by vehicle type entry coded as 18.

The total number of bus accidents that were reported during these 3 years was 3,875. Table 2 gives the number of these accidents by year for the six RTAs and the total state. The total number of public bus accidents does not appear to vary much by year.

Exposure Data Collection

VMT, which is considered to be the most common exposure measure, is used in this study. The VMT data used in this study were obtained from the Public Transit Division, Ohio Department of Transportation (ODOT).

Part of this research focuses on the accident experience of transit bus under three weather conditions of travel: no adverse weather, rain, and snow. *Climatological Data* is a monthly official publication of the National Oceanic and Atmospheric Administration that provides detailed climatic data for each state (*5*).

The authors want to compare the mean bus accident rates of the six major transit systems under different weather conditions. To derive this exposure measure easily, simply define a day with precipitation of more than 0.5 in. to be a rainy day and a day with snowfall of more 0.5 in. to be a snowy day. There might be both precipitation and snowfall over 0.5 in. in the same day; then simply define that day as a rainy day if there was more rain than snow or as a snowy day if there was more snow than rain. Table 3 gives a summary of the number of precipitation days with rainfall and snowfall over 0.5 in. for the six major transit system areas.

TABLE 3 Number of Days with Precipitation over 0.5 in., 1989–1991

Year	Rain/Snow Toledo	Cleveland	Akron	Columbus	Dayton	Cincinnati
1989	21/15	28/33	27/29	30/12	31/12	29/3
1990	30/14	41/19	48/16	41/9	42/8	38/2
1991	17/11	18/25	12/19	21/9	23/9	27/2

DATA ANALYSIS

Overall Accident Data Analysis

All of the bus and bus-related accident data, which were collected and provided by ODPS, are used to conduct a thorough analysis to explore the effects and distribution of various factors. After screening out incomplete and questionable accident reports, the authors developed a data base of approximately 3,860 accidents.

The yearly variation of accident occurrence for the 3 years does not show any distinct trend of accident frequency during this period. It only shows to have a little increase of occurrence in 1990 (Table 2).

Figure 2 illustrates the distribution of accident occurrence by month for the 3 years. Weather conditions that change by season may be hypothesized to have influence on accident occurrence, but they do not appear to be significantly correlated with each other. The greatest frequency of accidents occurred during May and October. The lowest frequency of accidents occurred during September.

The daily occurrence of accidents showed that there is no significant variation during the weekdays, but the accident occurrence dropped significantly on Saturday and Sunday, which may be due to the less intensive service frequency on these 2 days. Monday and Friday were slightly higher than the other days. On the basis of the concept of exposure, this result was expected.

Figure 3 shows the proportion of accident occurrence by RTA. Six major transit authorities contain more than 85 percent of the

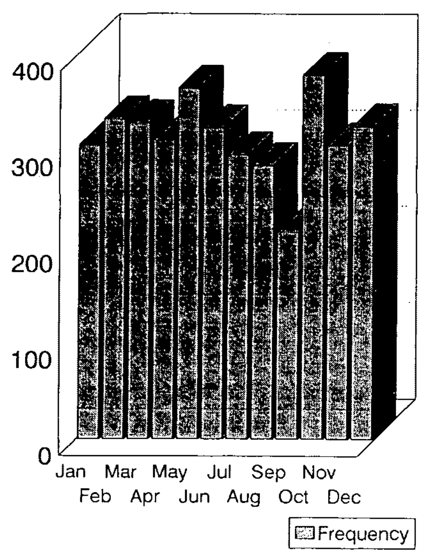

FIGURE 2 Distribution of accident occurrence by month.

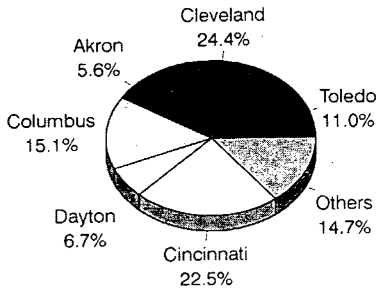

FIGURE 3 Distribution of accident occurrence by transit authority.

bus accidents that occurred in Ohio during the 3 study years. This phenomenon may be because the small urban and rural transit systems operate more vans instead of buses. Greater Cleveland RTA, which has the largest vehicle fleet (788 buses) and is the largest transit system in Ohio, had about one-fourth of the bus accidents that occurred in Ohio. The Cincinnati system had about one-fifth of the accidents. The Columbus and Toledo systems had similar proportions of the accidents, and the Akron and Dayton systems had lower proportions of the accidents.

Figure 4 shows the accident variation under different weather conditions. Almost 80 percent of the accidents occurred in clear weather, with 15 percent of the accidents in rain and 5 percent in snow. Although some studies indicated that rain and snow have influence on motor vehicle accidents, especially on passenger cars, it cannot be told from this figure about how weather conditions affect bus accidents.

Figure 5 is the distribution of accident occurrence on different pavement surface conditions. It shows that more than 70 percent of the accidents occurred on dry pavement, with 20 percent of the accidents occurring on wet and 5 percent occurring on ice- or snow-covered pavement.

The proportion of accident occurrence under different light conditions was examined. More than 80 percent of the accidents occurred in the daylight, and about 4 percent occurred during dawn and dusk. Only a small proportion (12.6 percent) of the accidents occurred in darkness with or without lights. This probably reflects that a few major transit systems provide full service during nighttime and that they also offer less intensive service frequency. Limitations in data preclude any further analysis of the accident rates under daylight and darkness, but it would be of interest to see if the accident rate increases significantly in darkness.

Figure 6 shows the proportion of accident occurrence by different types of collision. The three most common collision types are sideswipe (29.4 percent), angle (26.3 percent), and rear end

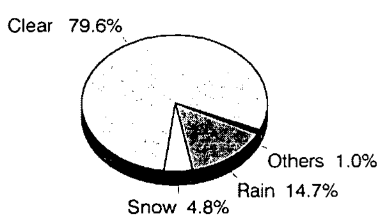

FIGURE 4 Distribution of accident occurrence by weather condition.

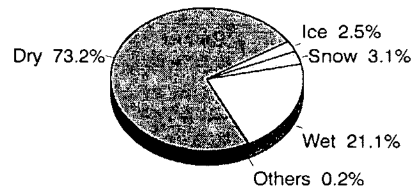

FIGURE 5 Distribution of accident occurrence by roadway condition.

(22.6 percent). These are followed by crashed with parked vehicle (9 percent) and crashed with fixed object (3.2 percent). These indicate that vehicle maneuvering or handling is a major factor in public bus accident occurrence.

The breakdown of proportion of the accidents by severity was carried out. Most accidents were property damage only. Only a very small proportion of the accidents (0.3 percent) resulted in a fatality. The data confirm that buses are one of the safest modes of transportation. Injury accidents, however, are a factor to consider.

In looking at the locations of the accidents, about half occurred at an intersection or intersection-related area, and the other half occurred at a nonintersection or other area (e.g., area of railway crossing and bridge). The proportion of accidents occurring at an intersection area appeared to be small when compared with the study done in the Chicago metropolitan area (2), where more than 70 percent of the bus accidents occurred at intersections. This may be because the Chicago metropolitan area is more urbanized than any of the cities in Ohio.

Analysis of Accident Rates Among Six Major Systems

A single-factor ANOVA problem involves a comparison of k population or treatment means, $u_1, u_2, \ldots, u_k$. The objective is to test H_o: $u_1 = u_2 = \ldots = u_k$ against H_a: at least two of the means are different. This analysis is based on k independently selected random samples, one from each population or for each treatment.

Although a single-factor ANOVA can be carried out to compare more than two population means, it has its own limitations and may need further analysis of data to identify the significant difference among the population means. Consider the case of $k = 3$ populations or treatments and null hypothesis H_o: $u_1 = u_2 = u_3$. If H_o is not true, there are four possible groups of the u's:

1. $u_1 = u_2$ and u_3 differs from these two,
2. $u_1 = u_3$ and u_2 differs from these two,

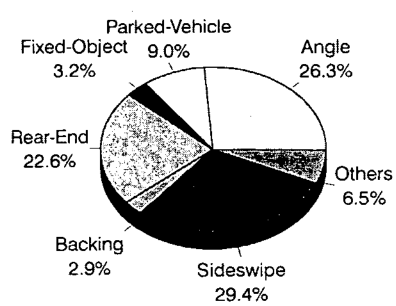

FIGURE 6 Distribution of accident occurrence by accident type.

3. $u_2 = u_3$ and u_1 differs from these two, and
4. All three u's are different from one another.

After H_o is rejected, an investigator would typically want to know which of these four groupings is most plausible. Therefore, following rejection of H_o, a further analysis may be necessary to identify differences among the u's. This is called a multiple comparisons procedure.

The Bonferroni multiple comparisons procedure is easy to understand and apply. The general idea behind this procedure is first to compute a confidence interval for the difference between each pair of u's. For example, in the case $k = 3$, an interval would be computed for u_1-u_2, another for u_1-u_3, and a third for u_2-u_3. After all such confidence intervals have been obtained, each one is examined to see whether it includes 0 or not. If the confidence interval does not include 0, then two corresponding u's are said to differ significantly from one another.

The Bonferroni multiple comparisons procedure is as follows: when there are K treatments or populations to be compared, first compute the following $K(K - 1)/2$ confidence intervals using the appropriate critical value based on error degree of freedom (MSE = mean square error).

For u_1-u_2: $\bar{X}_1 - \bar{X}_2 \pm$ (Bonferroni critical value)$(MSE/n_1 + MSE/n_2)^{1/2}$

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For $u_{k-1}-u_k$: $\bar{X}_{k-1} - \bar{X}_k \pm$ (Bonferroni critical value)$(MSE/N_{k-1} + MSE/n_k)^{1/2}$

Then two u's are judged to differ significantly if the corresponding interval does not include 0. This procedure guarantees that for (at least) 95 percent of all data sets, no means will be incorrectly judged significantly different.

The bus accident rates of the six major transit systems in Ohio will be compared to see if there is any difference of operation safety problem of the systems. The bus accident rates within each major system under different weather conditions will also be compared to see whether the weather conditions have a negative influence on transit bus operations. As discussed, a single-factor ANOVA, involving a comparison of more than two population or treatment means, is carried out to compare the bus accident rates of six Ohio major transit systems and the bus accident rates under different weather conditions. When H_o: all u's (bus accident rates) are equal is rejected in favor of H_a: at least two of the u's are different, then the Bonferroni multiple comparisons procedure is conducted for in-depth analysis of these bus accident rates to see if there is any significant difference of accident rates among these systems as well as to see if there is any significant difference of accident rates in various weather conditions.

Comparison of Accident Rates

In this study the bus accident rate can be simply defined as

Bus accident rate

$$= \frac{\text{Number of accidents involving at least one bus}}{\text{VMT generated by bus}} \tag{1}$$

The other way to evaluate the system safety performance sometimes used by transit operators is by using VMT generated by bus (Table 4) divided by number of accidents involving at least one bus. This measure indicates the distance between two bus accidents. Table 5 gives the average bus accident rates of the six Ohio major RTAs using these two measures based on the 1989–1991 bus accident data.

The VMT/accident rate illustrates the overall relative safety of bus use in Ohio. Cleveland and Dayton have a low accident/million vehicle miles (MVM) rate, Columbus and Akron are in the middle range, and Toledo and Cincinnati have higher rates.

Statistical Comparison of Accident Rates of Six Major Transit Systems

The authors want to compare the mean accident rates of the six major transit systems in Ohio, which are Toledo Area, Greater Cleveland, Akron, COTA (Columbus), Miami Valley (Dayton), and Southwest Ohio (Cincinnati). Tables 2, 4, and 5 give the basic bus accident data, VMT information and accident/MVM rates for the six major Ohio transit systems, respectively. These tables show that although there is some variability in accident frequency, VMT, and accident rate by year for each of the six systems, there is no major change or trend for any of them.

ANOVA is used to test the significance of differences among these mean rates. The null hypothesis tested is that there is no significant difference among the rates. Let u_{Tol}, u_{Cle}, u_{Akr}, u_{Col}, u_{Day}, and u_{Cin} denote the average bus accident. The results of an ANOVA table show that the computed F-value, 70.15, does exceed the critical value 3.11. So H_o is rejected at a 0.05 level of significance. The data suggest that there are differences in average accident rates among these six transit systems.

The statistical test result concludes that the average bus accident rates for these six systems are different. The Bonferroni multiple comparisons procedure is conducted. For the population $K = 6$, the Bonferroni multiple comparisons procedure requires that $K(K - 1)/2 = 15$ intervals be computed. From the computed Bonferroni t-

TABLE 4 VMT Information, 1989–1991 (100,000 mi)

Year	Toledo	Cleveland	Akron	Columbus	Dayton	Cincinnati
1989	6.391	25.085	4.050	9.768	6.999	11.376
1990	6.380	26.949	4.044	9.881	7.742	11.461
1991	5.976	25.534	4.597	10.368	8.942	11.959

TABLE 5 Bus Average Accident of the Six Ohio Major Transit Systems Using Measures of Accident per MVM and Miles per Accident

Rate	Toledo	Cleveland	Akron	Columbus	Dayton	Cincinnati
Year						
1989	24.10	12.56	18.27	19.14	12.29	23.29
1990	22.88	12.65	17.31	19.73	10.85	26.26
1991	21.25	11.20	15.88	19.39	9.84	25.42
Average						
Accident / MVM	22.74	12.14	17.15	19.42	10.99	24.99
VM / Accident	44,085	82,048	58,491	51,496	91,388	40,114

critical value table, the Bonferroni t-critical value for 15 intervals at a level of 0.05 is 3.65. The intervals are as follows:

For $u_{Day}-u_{Clc}$:

$$\bar{X}_{Day} - \bar{X}_{Clc} = (10.993 - 12.137) \pm 3.65(1.35/3 + 1.35/3)$$
$$= -1.144 \pm 3.65(0.949) = (-4.787,\ 2.499)^{1/2}$$

For $u_{Day}-u_{Akr}$: $(-9.804,\ -2.518)$

For $u_{Day}-u_{Col}$: $(-12.072,\ -4.786)$

For $u_{Day}-u_{Tol}$: $(-15.394,\ -8.108)$

For $u_{Day}-u_{Cin}$: $(-17.643,\ -10.357)$

For $u_{Clc}-u_{Akr}$: $(-8.66,\ -1.374)$

For $u_{Clc}-u_{Col}$: $(-10.928,\ -3.642)$

For $u_{Clc}-u_{Tol}$: $(-14.25,\ -6.964)$

For $u_{Clc}-u_{Cin}$: $(-16.499,\ -9.213)$

For $u_{Akr}-u_{Col}$: $(-5.911,\ 1.375)$

For $u_{Akr}-u_{Tol}$: $(-9.233,\ -1.947)$

For $u_{Akr}-u_{Cin}$: $(-11.482,\ -4.196)$

For $u_{Col}-u_{Tol}$: $(-6.965,\ 0.321)$

For $u_{Col}-u_{Cin}$: $(-9.214,\ -1.928)$

For $u_{Tol}-u_{Cin}$: $(-5.892,\ 1.394)$

Four intervals ($u_{Day}-u_{Cle}$, $u_{Akr}-u_{Col}$, $u_{Col}-u_{Tol}$, and $u_{Tol}-u_{Cin}$) include 0. So the bus accident rates of Miami Valley RTA and Greater Cleveland RTA, of Akron Metro RTA, COTA, and Toledo Area RTA, and of Toledo Area RTA and Southwest Ohio RTA are judged not significantly different, but all other pairs of u's are judged significantly different. This can be summarized by underscoring:

Transit System	*Average Accident Rate*
Dayton	10.993
Cleveland	12.137
Akron	17.154
Columbus	19.422
Toledo	22.744
Cincinnati	24.993

From the Bonferroni multiple comparisons procedure, one can tell that Miami Valley RTA and Greater Cleveland RTA are the two transit systems with the lowest bus accident rates in Ohio. For other systems, there is not enough evidence to distinguish the accident rates either among Akron Metro RTA, COTA, and Toledo Area RTA or between Toledo Area RTA and Southwest Ohio RTA, but one still can tell that Southwest Ohio RTA has a higher bus accident rate than Akron Metro RTA and COTA.

Statistical Comparison of Accident Rates of Six Major Transit Systems Under Different Weather Conditions

Weather condition is considered to have an influence on the occurrence of vehicle accidents, especially on passenger cars. From the previous results, it is hard to tell if weather conditions have an influence on the occurrence of bus accidents or not. To explore how weather influences bus accidents, these six major transit systems can be treated as a whole system.

There are three weather conditions: no adverse weather (clear), rain, and snow. These conditions are analyzed because few bus accidents occurred in fog or heavy wind conditions and because weather data were limited. To compare the mean bus accident rates of these six major transit systems under various weather conditions, separate the VMT data. According to the information given in Table 3, VMT data for six major transit systems under rain, snow, and clear days can be separated easily by their proportions. Then an ANOVA is used to test whether there are significant differences among these means or not. The null hypothesis tested is that there is no significant difference among means. Then the Bonferroni multiple comparisons procedure for the further analysis is conducted, if H_o is rejected at a level of 0.05 alpha test. Let u_{Clear}, u_{Rain}, and u_{Snow} denote the average bus accident rates for three weather conditions.

The results of the ANOVA table gave a computed F-value, 26.81, that exceeds the critical value 5.14. Obviously, H_o is rejected at level of significance 0.05. The data suggest that there are significant differences among the average accident rates in various weather conditions.

The statistical test concluded that the average bus accident rates in different weather conditions for these six transit systems are different. From this outcome, the authors are interested to know in what weather condition the bus drivers experience higher risk of accident. The Bonferroni procedure is conducted for this purpose.

For the population $K = 3$, the Bonferroni multiple comparisons procedure requires that $K(K - 1)/2 = 3$ intervals be computed. The Bonferroni t-critical value for three intervals at a level of 0.05 is 3.29. The intervals are as follows:

For $u_{Clear}-u_{Snow}$:

$$\bar{X}_{Clear} - \bar{X}_{Snow} = (15.182 - 17.804)$$
$$\pm 3.29[(8.91/3) + (8.91/3)]$$
$$= -2.622 \pm 3.29(2.437) = (-10.64,\ 5.396)^{1/2}$$

For $u_{Clear}-u_{Rain}$: $(-24.614,\ -8.578)$

For $u_{Snow}-u_{Rain}$: $(-21.992,\ -5.956)$

Only the interval for $u_{Clear}-u_{Snow}$ includes 0. The bus accident rates in snow and clear weather are judged not significantly different, but all other pairs of u's are judged significantly different. The corresponding underscoring is shown here:

Weather Condition	*Average Accident Rate*
Clear	15.182
Snow	17.804
Rain	31.778

The Bonferroni procedure shows that there is no significant difference between average bus accident rates in clear days and snow, but both accident rates in snow and clear weather differ significantly from the rate in rain. This means that the bus drivers in these six Ohio major transit systems could experience a higher risk of accidents in rain than in snow and clear weather. This also shows that rain could be an important factor for the occurrence of a bus accident.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Approximately 3,860 bus accidents that occurred during 1989–1991 were analyzed to identify factors contributing to bus accident occurrence. For the entire data set, examination of yearly and monthly accident totals could not identify any trend in accident occurrence. From the examination of daily variation, the bus accidents dropped dramatically on Saturday and Sunday, reflecting the less intensive service frequency during these 2 days. From the hourly variation, the accidents appeared to have two peaks occurring at the morning and evening rush hours (7:00–8:00 a.m. and 3:00–5:00 p.m.).

From the analysis of the contribution of environmental factors to the accident occurrence, weather and pavement conditions could be contributing factors, as 79.6 percent of the accidents occurred during clear weather and 73.2 percent of the accidents occurred on dry pavement. These findings are similar to the study done in Chicago metropolitan area (*2*). Bus accidents dropped significantly during night hours, this also reflects the less intensive service frequency in the night hours.

The analysis of types of bus accidents indicated that sideswipe, angle, and rear end were dominant; they contained almost 80 percent of the bus accident totals. The severity level was generally low—there were only 13 bus accidents (0.3 percent) with a fatality. Most of the accidents were property damage only (67.6 percent).

From the analysis of accident locations, about half of the accidents occurred at an intersection or intersection-related area and the other half occurred at a nonintersection or other areas (e.g., area of railway crossing or bridge passing over or under). The proportion of accidents that occurred at an intersection area was smaller in comparison to the study done in the Chicago metropolitan area (more than 70 percent of the bus accidents occurred at intersections in Chicago).

The comparisons of mean accident rates of six major transit systems indicated that Miami Valley RTA and Greater Cleveland RTA are the two transit systems with the lowest bus accident rates in Ohio. For other systems, there is not enough evidence to distinguish the accident rates either among Akron Metro RTA, COTA, and Toledo Area RTA or between Toledo Area RTA and Southwest Ohio RTA. Southwest Ohio RTA still can be judged to have a higher bus accident rate than Akron Metro RTA and COTA.

This analysis does not show that the Greater Cleveland RTA, Southwest Ohio RTA, and COTA, the three largest transit systems in Ohio, have significantly higher accident rates. Therefore, the level of urbanized area can be concluded to have no significant contribution to bus accidents in Ohio for these large urban systems. From the comparison of mean accident rates under different weather conditions, rain is found to be a contributing factor to bus accidents.

Recommendations

A follow-up study should take a longer-term accident period and look at original accident reports to determine more specific results and accident trends. The bus accident rates of Southwest Ohio RTA and Toledo Area RTA are found to be higher than those of all other major transit systems in Ohio. The reasons that these two systems have the high accident rates should be investigated further.

Accident type sometimes is considered to have direct relationship to accident severity. Although a bus is one of the safest transportation modes, it might be interesting to look at their relationship in the future.

Finally, it must be remembered that although there are different accident frequencies and characteristics among the six largest public transit authorities in Ohio, the authors are looking at relative differences. Overall, in Ohio, public bus use is a safe mode, especially considering the level of severity.

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PART 2

Electric Trolleybus

Line Evaluation Criteria for Electric Trolleybus Application

ELIANE GUILLOT AND SUSAN PHIFER

The method used to evaluate candidate electric trolleybus lines in Los Angeles is described. The effort was aimed at defining which lines should first be implemented, in support of the regional air quality mandate. Some may view electrification as a capital enhancement to an existing motor coach plant, but this intense 3-month evaluation phase focused on its operations and maintenance aspects. The evaluation team analyzed data for packages of three to four lines and looked at the future network layout and ensured trolleybus compatibility with transit maintenance facilities plans. The review culminated with a formal screening, followed by further refinement of the top-rated packages. About a third of the original packages were recommended for inclusion in the draft environmental impact statement. Operations issues covered the ridership impacts of potential line truncations if only the core leg of a regional route is electrified. Also examined was how future electric trolleybus lines might interface with other modes: express bus, commuter rail, and urban rail transit. The key package selection criteria are displayed in a sample evaluation matrix. These criteria were first tailored to the Los Angeles planning context. The evaluation framework is broadened for transferability to other cities, enabling the densest segments of local bus lines to be upgraded.

The team approach used in early 1992 to select the most viable motor coach lines for near- to mid-term electrification in Los Angeles is summarized. The paper presents the process used by the Route Selection Task Force in defining, fine-tuning, and testing evaluation criteria. Throughout the route selection phase, the multidisciplinary nature of the team was a strong catalyst in reaching a consensus. This was a critical path approach, chosen to fit within the very short time span of this intense effort and facilitate scoping for the subsequent engineering and environmental reviews.

The evaluation team had approximately 20 members, including the following participants:

1. Planning, operations, scheduling, and maintenance facilities representatives from the Southern California Rapid Transit District (SCRTD), since merged with the regional agency funding this effort [Los Angeles County Transportation Commission (LACTC)] into a new agency, called the Los Angeles County Metropolitan Transportation Authority, hereby referred to as MTA;
2. Planning staff from the Long Beach (Public) Transit System and the Montebello Municipal Bus Lines, two municipal operators involved in this project, and resulting from a survey of the nine municipal fixed-route systems run in Los Angeles county;
3. Programming staff and public participation specialists from the LACTC and the SCRTD, since combined within the new MTA structure;
4. Electrical engineering, vehicle procurement specialists from the consulting team, led by ICF Kaiser Engineers with operation, planning, and base conversion support supplied by Parsons Brinckerhoff; and
5. Environmental and urban design subconsultants to ICF Kaiser Engineers, who first reviewed alternatives to be studied, then gave technical and field support to the 9-month development of the draft environmental impact report.

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EVALUATION APPROACH

Overview

The approach was tested over a very short time span (less than 3 months) and within the unique operating and funding context of Los Angeles. Still, it is expected to be transferable to other North American cities. The framework can help other transit planning and operating bodies in their local decision making about the potential for placing the overhead wire, electric trolleybus technology along corridors already served by motor coach lines. Many factors were addressed in the Los Angeles setting. Not all these factors may directly pertain to other places with either smaller urban areas or less dense local transit corridors.

First, the trolleybus route selection criteria developed in Los Angeles were drawn from performance measures used in transit service planning, route evaluation, or line restructuring (*1*). Quantitative measures already exist for most of these familiar transit concepts and apply equally to other vehicle technologies in fixed-route bus line applications. The measures ease the data collection and analysis. Adopted standards already used by the operator provide explicit values for target or threshold levels. In most cases, they also simplify the interpretation of the quantitative results, since the corresponding measures are monitored regularly.

Some line-level quantitative measures needed refinement. This occurred when only a portion of a line was proposed (a segment within a longer line, or only the local portion of a route combining local and express services along the same corridor). In some cases several lines, serving the same geographical sector and linked to a common operating and maintenance base, needed to be studied together. This was done by examining ''packages'' of lines instead of single lines.

Also found were elements, relevant to electrification potential or merit, that could not be quantified. Several lines were evaluated in the broad domain of public acceptance, goodwill from the local jurisdictions expected to be involved along the candidate lines, and local and regional consensus building—all of which factors were much more qualitative in nature. Overall, a careful compromise was needed to weigh the pros and cons of recommending a single line or phasing an optimal package of the most promising lines.

The main theme was to maximize opportunities for near-term electrification in line with regional air quality control measures. Such measures are regionally established by the Southern California Air Quality Management District. In response to the control measures, the team was directed to assess where the most promising line grouping might be, as well as which ones (or which core parts) would lend themselves most easily to an initial deployment of trolleybuses in Los Angeles. Other cities might be less eager to proceed at such a fast pace, partly because of their less pressing air quality issues—issues worsened in Los Angeles by massive urban sprawl and natural topography. They also may be less eager because of a local preference for low-polluting, alternative-fuel technologies over electric trolleybuses.

Objectives

The objectives of the route selection phase (2) were as follows:

- Identify major opportunities for (or potential obstacles to) the near-term electrification of the candidate lines or line segments and assess the level of community acceptance for this program via an extensive outreach effort targeted to the cities and communities affected by the proposed lines.
- Consolidate 20 candidate lines into several packages composed of two to four lines each and thus facilitate the review of their cumulative potential for near-term or future electrification. The purposes of combining routes into packages were to assess the overall performance of each package relative to isolated lines and to maximize opportunities for an optimal trolleybus network, capable of phased implementation and cost-effective operations.
- Define conceptually the key operating and physical parameters for each package. This aspect of the route selection phase required development of preliminary service plans and scheduling and coach assignment simulations for those packages that required major service restructuring instead of minor revisions to existing services.
- Compare the performance of the packages according to a set of agreed-on criteria and state the main reasons for recommending the most promising packages. The next step was to select which parts of the lines, identified within such packages, would be most suitable for the start-up phase of the Los Angeles demonstration.

Screening Criteria for Line Electrification

The evaluation criteria agreed on by the Route Selection Task Force and the Electric Trolleybus Coordinating Committee were the following:

- *Weekday headways of 15 min or less*: these represent current headways at peak and base periods on the candidate lines. If a line needed to be truncated or modified, the remaining trolley and nontrolley segments were assumed to operate with headways similar to current timetables on each leg.
- *Vehicle service hours per route mile*: the trolleybus service intensity or density indicated which lines would remove the maximum number of diesel bus trips from the road, especially those trips with many stops and starts resulting in slower speeds (or more service hours). The slower progression would result from traffic congestion as well as long dwell times at zones with high numbers of passenger boardings and alightings.
- *Cost-effectiveness relative to air quality benefits*: this was measured by the incremental annualized cost per pound of total emissions reduced—that is, when comparing the proposed trolleybus improvements to methanol-powered coach replacement on the candidate lines and reflecting some inherent savings (or added costs) due to the changes warranted by grouping lines in a package. If some nontrolleybus component was still needed, its contribution in pollutants emitted was treated as a disbenefit and any operations and maintenance costs above current operations were taken into account.
- *Geographic coverage*: the areas served and the general orientation of each line in a package were identified and mapped. The objective was to ensure a broad geographic coverage, itself a policy-oriented concern expected to prevail in a very large urbanized area like greater Los Angeles.
- *Scheduling and operations*: this looked at several operational and routing parameters as well as aspects unique to some lines. These parameters included current layout of the lines for their suitability or lack of suitability for trolleybus conversion (example: circuitous path, multiple branches, intermittent closures of route along current alignment for special events accommodations); potential for creating 100 percent trolleybus lines and maximizing the use of common wire segments in the Los Angeles central business district (LACBD) or other activity centers; current mix of local and limited services and their accommodation under the trolleybus program; lack of compatibility with freeway express running, limiting the initial phase of electrification to nonfreeway segments.
- *Impact on patronage*: the main focus at the route selection phase was to quantify the potential effects of forced transfers between trolley and nontrolley services as imposed by the rule of first electrifying only within a nonfreeway environment. The lines where a forced transfer would not occur as a result of electrification were generally expected to attract new riders on the previous motor coach service.
- *Proximity to operating base*: the intent was to minimize the need to install long stretches of nonrevenue wire while not adding to current deadhead distances with the introduction of trolleybus service. As much as feasible, the authors tried to minimize any marked increase in deadhead time over the current motor coach service plan. Lines identified in the same package tended to overlap in the core of the geographical sector served; this facilitated sharing a common division and nonrevenue wire segment for local site access and egress. The detailed routing plans for the preliminary engineering phase will need to optimize such site-specific assumptions. No attempt was made at testing potential savings in annualized costs associated with optimal routing paths among nonrevenue legs of lines in the same package. Such issues become more crucial for phasing the gradual implementation of the project.
- *Other factors*: the miscellaneous category included unavoidable conflicts (requiring periodic detours) with major events, interface and local feeder potential with existing or committed rail stations, as well as a corridor-level assessment of compatibility with other public works, roadway, or utility upgrade projects. In addition, community support from local jurisdictions was included. Relevant to gauging the local acceptance by affected jurisdictions were the types of support contemplated, for instance,

local commitment of financial support as well as local improvements supportive of transit service delivery such as preferential treatment for trolleybuses along streets and arterials proposed for electrification, urban design features along bordering sidewalks or street medians, or other operational measures facilitating bus stop or transit center layout.

DESIGN OF LINE PACKAGES

Sixteen packages were developed using various combinations of the 20 candidate lines. The review of these packages was based on the line evaluation criteria just given. In sorting among these candidate lines, the cumulative benefits of grouping specific lines or line segments were assessed. Several opportunities arose for major line restructuring as well as for potential service increases along some line segments. Typically, the proposed trolleybus services were defined to maintain service levels (i.e., coverage and typical weekday headways) equivalent to current levels on the affected motor coach lines.

The proposed grouping of the candidate lines into different packages responded to the following planning objectives:

- Strive for line proximity to one or more active operating division(s) expected to be retrofitted for trolleybus service, inspection, heavy maintenance, storage, and operations and dispatch. Assess the ability of lines in the same package to share the same division, even if it means reassigning an existing line to a new site (i.e., a change in current practice).
- Look for opportunities among lines in the same package to share overhead wire systems in revenue service, both within and outside LACBD. The greater the number of lines with a common segment, the more economical the construction and the maintenance of their overhead catenary system relative to the total length of the package. Preliminary paths of nonrevenue wire needs were laid out for sharing nonrevenue segments among lines in the same package.
- Analyze the proposed conversion of limited service (i.e., skip stop running on designated segments of major arterials) to local service. This change was tempered by the potential disbenefit of causing noticeable travel time increases at peak or midday hours along key route segments. In such cases, maintaining the integrity of the limited service was deemed to warrant the provision of double wire for reliable trolleybus passing. In other cases, the proposed electrification would affect only the local service components, whereas the limited service would rely on nontrolley technology.
- Minimize the potential to lower interline savings (in number of peak coaches), currently achieved via shared coach and driver assignments among different lines close to each other. This was considered explicitly for several packages, whether a candidate trolleybus line was interlined with another motor coach–only line or whether the limited portion of a route was not proposed for electrification (while the local portion was a promising candidate). Conversion to methanol-powered coaches offers more operational flexibility in this regard, as long as fueling provisions are made at all affected divisions.
- Compare the known capacities of active operating divisions with the estimated number of active trolleybuses in each package. This early assessment assumed compatibility between trolleybus and nontrolleybus fleets or the ability to mix technologies at the same maintenance site. Also assumed at this conceptual phase was the uniform use of standard-length (40-ft) trolleybus coaches among all the packages.
- Optimize intermodal connections with existing and programmed light rail, heavy rail, commuter rail, and other municipal or regional bus and rail transit services. This was reflected in the recommended trolleybus routings or route deviations for enhanced transfer opportunities.

DEFINITION OF SELECTED PACKAGES

Now the trolleybus evaluation is illustrated for three distinct packages. Highlighted are routing definition, service parameters, and local land uses along their respective lines (*3*). Briefly stated are unique aspects of each package and special issues raised by operations, maintenance, or multimodal integration. Such points supplement the quantitative results by placing the findings in the Los Angeles context. If one applied the same criteria elsewhere, a somewhat different interpretation might prevail to reflect local issues.

Package P-5: Description of MTA Lines 30/31 and 45

Package P-5 combines two lines with a common path through the LACBD; it covers 26 mi. Each line operating plan is summarized here.

As shown in Figure 1, Lines 30/31 follow West Pico Boulevard in West Los Angeles. Land uses are almost exclusively retail in

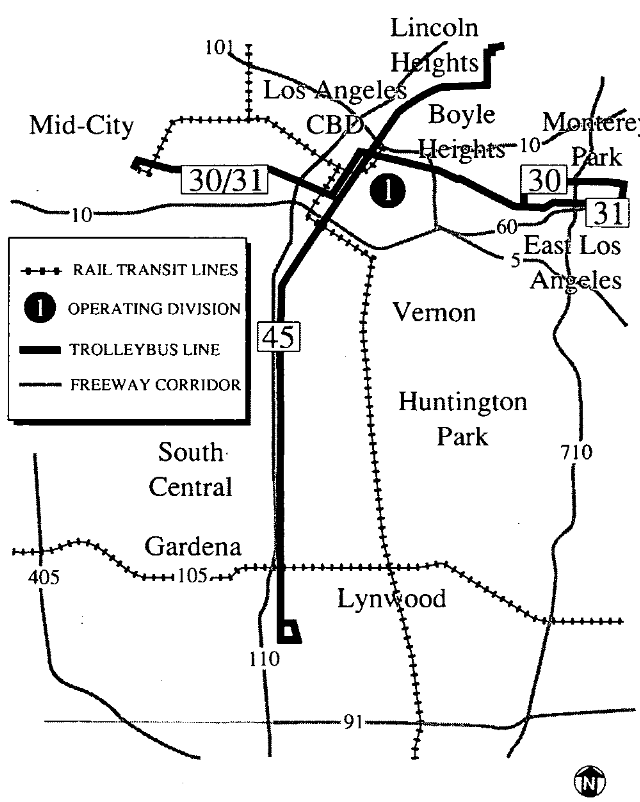

FIGURE 1 Package P-5 layout.

this segment of the route common to Lines 30 and 31. Through the LACBD, both lines follow the same path along Broadway (north-south penetration of the LACBD) between Pico Boulevard and First Street. The downtown segment still has a strong retail element with a mix of institutional, commercial, and office buildings, in the core part of Broadway.

To the east of the LACBD, Line 31 runs east-west along East First Street and terminates via a short loop along Atlantic Avenue, Floral Drive, Collegian Way, and Riggin Street. Land uses in the Boyle Heights community consist of small lots with a mix of residential, neighborhood retail, and open space. Within the unincorporated part of East Los Angeles and the city of Monterey Park, land uses are mostly residential. Line 30 follows an alternative branch from the trunk route on First Street to the east of Rowan Avenue via Hammel Street, Brannick Avenue, and Floral Drive. Both lines were proposed for electrification, even though the Floral Drive branch of Line 30 had somewhat higher boardings than the eastern leg of Line 31.

The weekday service span of Lines 30/31 is about 23 hr (from 4:30 a.m. to 3:40 a.m.), with peak headways of 7 min and base headways of approximately 15 min. The peak pullout requirement is 42 buses.

Lines 45/46/345 operate north-south along the Broadway corridor. Line 45 follows Broadway as far south as Rosecrans Avenue, with the Line 345 limited runs (peak period only) between Imperial Highway and the LACBD. Current travel time savings between Imperial and Pico Boulevard are approximately 9 min for the limited over the local trips. For this package, the Line 345 service was assumed to continue in nontrolleybus mode, thus electrifying only the Line 45 local service.

To the north of the LACBD, Line 46 currently uses the same path as Line 45 to the intersection of North Broadway and Griffin. The Line 46 branch, running through the Montecito Heights neighborhood, was not assumed to be electrified, with the local part of the service along Griffin replaced by an existing Line 255. Patrons bound for the LACBD would transfer to the Line 45 trolleybus service on North Broadway. The northernmost leg of Line 45 would be electrified along Lincoln Park Drive, Flora Avenue, Sierra Street, Mercury Avenue, and, turning around, at Collis Avenue and Huntington Drive, a major bus transfer node. Although this leg of Line 45 is quite circuitous, the very productive segment was considered worthy of electrification.

The Line 45 service span is slightly less than 24 hr, with peak headways of 7 min and base headways of approximately 15 min. The peak pullout requirement for Line 45 only is 24 buses.

As shown in Figure 1, Line 45 follows Broadway in each direction. The same LACBD path as now used was assumed for this package with common wire along the full length of Broadway between Pico Boulevard and First Street.

This package raises service development issues along the future rail extension corridors. The western terminus of Lines 30/31 is adjacent to the proposed Red Line interim terminus at Pico and San Vicente Boulevards. This may result in a shift of current bus riders to the rail service for a faster access to the LACBD area, as well as possibly a need to shorten base headways (from the current 15-min service) to provide more convenient feeder bus connections in the base period. The East Los Angeles routing of Lines 30/31 follows First Street, which parallels one of the rail alternative alignments (between Union Station and Indiana Avenue) defined by the recent MetroRail Eastside Extension AA/DEIS. Thus, the implementation of this subway extension may affect the future routing and service headways of Lines 30/31 along First Street.

Line 45 is expected to warrant change in its southernmost routing for feeder access to the 117th Street Green Line station and the Harbor Transitway. Ending the electrified route at this bus-rail transfer node is one service design option. Another option is to divert Line 45 from Broadway to an off-street transfer location west of Broadway. Current bus headways along this portion of the line may need to be shortened for more convenient local feeder bus access to both new regional transit facilities.

Package P-8: Description of MTA Lines 40 and 204.

Package P-8 combines two north-south lines, only one of which serves the LACBD. It covers a total of 30 mi. Each line operating plan is summarized here.

As shown in Figure 2, Line 40 follows Martin Luther King Jr. Boulevard, Crenshaw Boulevard, and Hawthorne Boulevard. It connects the LACBD (via the north-south Broadway corridor) with a mix of industrial, commercial, and small office buildings along the middle part of the route. Pockets of residential areas are served near the southern terminus at the South Bay Galleria Transit Center, part of a regional shopping mall in the city of Redondo Beach.

The weekday service span on Line 40 is 24 hr, with peak headways of 9 min and base headways of approximately 12 min. The peak pullout requirement for Line 40 is 55 buses.

As shown in Figure 2, Line 204 currently runs north-south on Vermont Avenue from Imperial Highway in the South Bay area

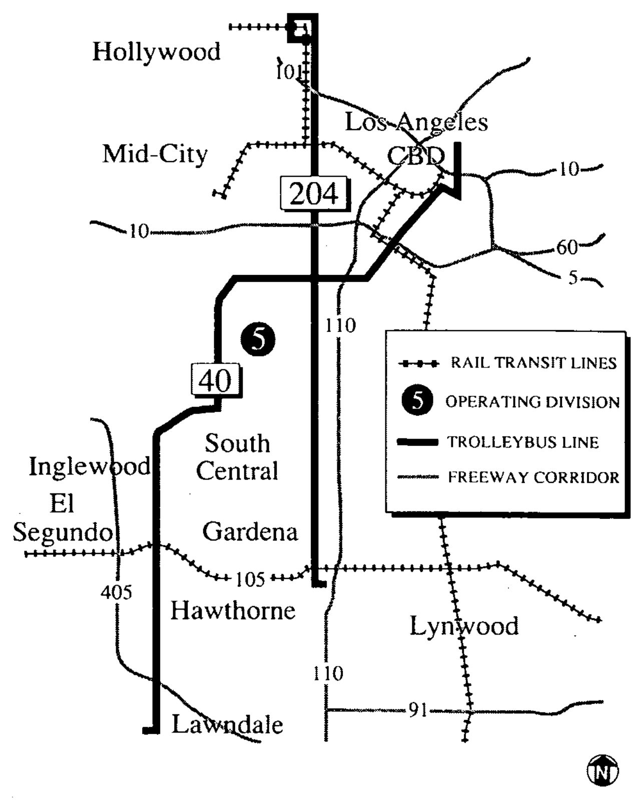

FIGURE 2 **Package P-8 layout.**

to Hollywood Boulevard in Hollywood. Line 204 does not serve LACBD directly, although transfers to the future Red Line subway stations along Vermont Avenue would provide convenient access to downtown from the northern part of this trolley corridor. The north-south corridor is bordered mostly by retail land uses, sparsely mixed with small pockets of residential and open space and commercial activities.

Besides the local 204 motor coach service, Line 354 currently provides limited-stop service along Vermont from Melrose to Manchester Avenue. Current travel time savings between these two limited stops is approximately 8 min for the limited over local trips. For this stage of route refinement, the limited 354 service was assumed to be electrified and converted to local service. This change was estimated to require an extra two peak coaches over current weekday needs.

Line 204 will feed the Red Line at future subway stations located at Vermont Avenue and Wilshire, Beverly, Santa Monica, and Sunset Boulevards. Under the proposed rail feeder plan, there is no change to Line 204 routing, whose northern path was already altered for permanent feeder bus access to this leg of the heavy rail network.

The Line 204 weekday service span is 24 hr, with peak headways of 6 min and base headways of approximately 10 min. The peak pullout requirement for Line 204 is 39 buses.

This package can be integrated with the near-term development of the initial Green Line east-west corridor along the new Century Freeway median. Line 204 will serve the Green Line station near 117th Street and Vermont Avenue. Line 40 will also feed the Green Line near Imperial Highway and Hawthorne Boulevard. Line 40 current peak headways of 12 min may need to be shortened for more convenient feeder service to the regional rail system. Long-term opportunities for a southern extension of the Green Line along Hawthorne Boulevard might point to the need for first electrifying Line 40 only as far south as Imperial Highway.

Package P-9: Description of MTA Lines 70 and 92/93

Package P-9 combines two local lines and covers a total of 35 mi. Each line operating plan is summarized here.

As shown in Figure 3, Line 70 begins in the LACBD and uses a circuitous path through the Boyle Heights and City Terrace communities. The predominant land uses in this initial leg are residential. The line then runs east-west along the Garvey Avenue corridor, which parallels the San Bernardino Freeway up to the eastern terminus at the El Monte Busway Station. Land uses along Garvey Avenue are mostly neighborhood retail, especially east of Fremont Avenue.

Within the LACBD, this line follows the north-south Spring Street corridor (parallel to Broadway) between Sunset Boulevard and 12th Street. A loop at the southern edge of the LACBD serves the convention center and the Blue Line Station at Pico Boulevard and Flower Street. At this stage of development, the loop was assumed to be electrified, although the environmental review of potential traffic conflicts with convention center activities has since led to proposing a relocation of the loop to a more remote site.

Line 70 weekday service span is 24 hr with peak and base headways of 10 min. The peak pullout requirement for Line 70 is 22 buses.

As shown in Figure 3, Lines 92/93 currently operate from LACBD north to the city of Glendale along Glendale Boulevard. They continue north along Brand and Glenoaks Boulevards through the cities of Sun Valley and San Fernando. Then Line 93 deviates from Line 92 along a branch on Allesandro Street and Riverside Drive, to the south of the Golden State Freeway in the Silverlake neighborhood of Los Angeles.

In view of the extensive coverage of this line (full length at more than 26 mi between the LACBD and the north terminus), only the southernmost portion to Olive and Glenoaks in Burbank was originally studied as a viable trolleybus candidate. Yet in or-

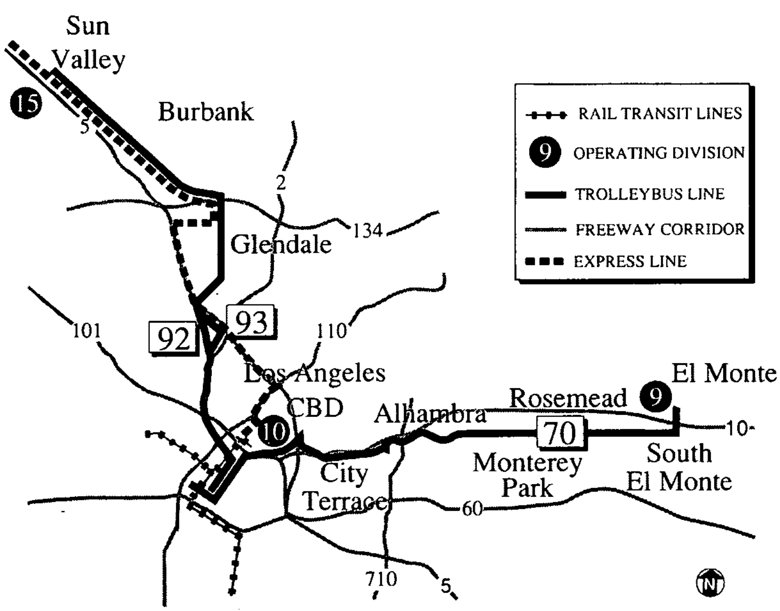

FIGURE 3 Package P-9 layout.

der to use an existing operating division along the corridor, the authors opted to extend the proposed trolleybus coverage further north. This resulted in a net line coverage of 20.7 mi for the proposed trolleybus service.

The service span of Lines 92/93 is 24 hr with peak headways of 10 min and base headways of 15 min, south of the Burbank CBD. Current base headways on Lines 92/93 to the north of Burbank are approximately 24 min, with current peak-period headways on Line 410 in the range of 15 to 30 min. Peak pull-out requirements for truncated Lines 92/93 are 16 coaches.

The proposed truncation of Lines 92/93 would be mitigated by an increase in current service levels along Line 410. This line follows the same Glenoaks Boulevard corridor as Lines 92/93 within the San Fernando Valley and becomes an express line along the I-5 freeway from Colorado Street near Griffith Park to the LACBD. Although current service on Line 410 runs only in the peak periods, the trolleybus conversion would introduce all-day, nontrolley service along Glenoaks Boulevard between Hubbard Street in San Fernando and Colorado Street in Glendale to replace local service deleted on the shorter Lines 92/93 runs. Yet, this extension of the service span for Line 410 results in a net increase of six extra a.m. peak and four extra p.m. peak coaches for the new service (i.e., combined trolley along shorter Lines 92/93 and nontrolley along all-day Line 410). This change would warrant an additional 104 platform hours on a typical weekday for the family of Lines 92/93/410, or a 38 percent increase over current service supply without offering any more frequent runs than today.

In the LACBD, Lines 92/93 operate on Temple, Spring, and Main Streets in a counterclockwise loop. Under this package, the future trolleybuses would operate in each direction on Spring Street. The LACBD trolleybus revenue wire shared by Lines 70, 92 and 93 would follow Spring Street between Pico and Sunset Boulevards.

Summary of Results for Selected Packages

Table 1 presents a summary of the evaluation results for each of these packages. It shows the composition and length of each package as well as the planning assumptions made on operating division assignments. Current weekday service levels are given for peak and base headways by line. On the basis of these current service levels, the corresponding service intensities in weekday vehicle hours per route mile are shown. Also given in Table 1 are the net cost per pound of emissions reduced, an abbreviated label for geographic coverage, and estimates of peak trolleybus coaches, active fleet sizes, and anticipated effects on patronage.

INTERPRETATION OF TECHNICAL FINDINGS

The evaluation team reviewed all the technical findings, compared results among the 16 packages, and recommended a total of 5 to 6 packages. The recommendations were made for the environmental analysis to focus on those packages contemplated for the first phase of the trolleybus program (*4*). Results of the team review are summarized for the three packages just described.

Package P-8

Package P-8, which consists of MTA Lines 40 and 204 in full, was strongly recommended for the first phase. The indicators for service intensity and cost-effectiveness were both high relative to the full set of packages. Table 2 indicates that P-8 ranks third in service intensity and fourth in cost-effectiveness. Both lines serve heavily used transit corridors along major north-south arterials, which connect several sectors of the MTA service area. Both lines could share the same operating division in the South Bay. When the Green Line trains begin in revenue service, there will be potential to increase local service frequency along the Hawthorne Boulevard segment of Line 40. This would further increase the indicator for service intensity. In view of those strengths, neither the lack of common revenue wire among both lines nor the proposed replacement of limited service by local service along Vermont Avenue (Line 354 becomes same as Line 204) were judged to be significant weaknesses.

TABLE 1 Electric Trolleybus Route Selection: Aggregate Data for Selected Packages (*2*)

	Package Composition (Length of full package)	Current Service Levels Weekday Headways By Line: Line	Base (Minutes)	Peak (Minutes)	Weekday Vehicle Hours Per Route Mile	Net Cost Per Pound Of Emissions Reduced	Geographic Coverage
P5	MTA 30/31, and 45 (26.2 miles)	30/31 45 345	15 15	7 7 7 to 8	30.7 (gross) 32.6 (with shared wire)	$29	LACBD, SGV, Southeast, Westside, East LA
P6	MTA 30/31, 40 and 45 (39.0 miles)	30/31 40 45 345	15 12 15	7 9 7 7 to 8	32.7 (gross) 37.8 (with shared wire)	$29	LACBD, East LA, SGV, Southeast, Westside, South Bay
P8	MTA 204 and 40 (29.7 miles)	204 40	10 12	6 9	35.8 (gross)	$32	LACBD, Westside, South Bay
P9	MTA 92/93 and 70 (34.9 miles)	92/93 410 70	15 10	10 15 to 30 10	13.2 (with shared wire)	$104	LACBD, SGV, SFV
P10	MTA 30/31 and 70 (26.4 miles)	30/31 70	15 10	7 10	26.1 (gross) 27.8 (with shared wire)	$38	LACBD, SGV, Westside, East LA

(*continued on next page*)

TABLE 1 (*continued*)

	Package Composition (Length of full package)	Operating Division Number (Rated Capacity in Number of Coaches)	Peak Trolley Coaches	Active Coaches Estimate (% of Division Capacity)	Impact Upon Patronage (Based on current weekday segment level counts)	Average Distance To Operating Division (Miles)
P5	MTA 30/31, and 45 (26.2 miles)	MTA Division 1 at Sixth and Central (170)	66	76 (45%)	Potential for reduction along Westside leg along Pico with future opening of proposed Pico/San Vicente Red Line interim terminus.	0.85
P6	MTA 30/31, 40 and 45 (39.0 miles)	MTA Division 1 at Sixth and Central (170) and MTA Division 10 at Macy and Mission (238)	123	150 (30% for both combined)	Similar to P-5, plus potential for reduction with 46 leg replacement by 255 local and transfer to LACBD bound trolleys at North Broadway.	0.75
P8	MTA 204 and 40 (29.7 miles)	MTA Division 5 at 54th and Van Ness (235)	94	108 (46%)	Potential for reduction with 354 replacement by local only trolleybus runs.	1.13
P9	MTA 92/93 and 70 (34.9 miles)	MTA Division10 at Macy and Mission (238) and small part of MTA Division 9 at Santa Anita and Ramona (near El Monte Station)	38	44 (17%)	Approximately 510 (8% of NB riders) and 890 (14% of SB riders) patrons forced to transfer in Sunland along Line 92/93.	0.88
P10	MTA 30/31 and 70 (26.4 miles)		64	74 (31%)	Positive, except for Westside leg along Pico with future opening of proposed Pico/San Vicente Red Line interim terminus.	0.75

Package P-5

Package P-5, which consists of MTA Lines 30/31 and 45, was only recommended as part of a larger Package P-6. As indicated in Table 1, P-6 combines the two lines, defined for package P-5, with Line 40 (also part of the package P-8). Per Table 2 estimates of shared wire, the service intensity indicator increased from 32.6 to 37.8 vehicle service hours per route mile, when adding Line 40 to P-5. But P-5 by itself was found to be equally cost-effective to P-6 as a whole. Overall P-6 ranked second (service intensity), while P-5 ranked fifth; P-6 and P-5 ranked first for cost-effectiveness. Without using constraints on capital funds for the trolleybus project, the larger Package P-6 would have greater air quality benefits than P-5. P-6 would give access options to a zero-polluting fleet to a greater number of transit riders.

Looking at smaller differences between Packages P-5 and P-6, the three lines proposed for P-6 would share 6.0 mi of revenue wire along Broadway within and south of the LACBD. This common wire benefit is reduced to 1.5 mi among the two lines proposed for P-5. Trolleybuses under P-5 only could share a single operating division east of the LACBD. The larger fleet size for P-6 (i.e., about twice the P-5 active fleet) would warrant a split

TABLE 2 Overall Ranking of Aggregate Measures (2)

Trolley Revenue Service Intensity Rank (in VSH*/Rte Mile)	Package	VSH*/ RteMile Value	Possible Clusters
1	P-4	48.1	30 or more
2	P-6	37.8	
3	**P-8**	**35.8**	
4	P-7	33.9	
5	**P-5**	**32.6**	
6	P-1	29.6	25 to 30
7	P-3	29.4	
8	P-16	28.6	
9	P-2	27.2	
10	P-10	26.1	
11	P-11	25.5	
12	P-12	21.8	20 to below 25
13	P-14	19.5	below 20
14	P-13	16.8	
15	P-15	16.3	
16	**P-9**	**13.2**	

* *VSH stands for Vehicle Service Hours*

Cost Effectiveness Relative to Air Quality Rank (in Incremental $/Lbs Reduced) (1)	Package(s)	Cost Effectiveness Value ($)	Possible Clusters
1, 2, 3	P-4, **P-5,** P-6	**29**	$35 or less
4	**P-8**	**32**	
5, 6	P-3, P-16	35	
7	P-10	36	$36 to $75
8, 9	P-7, P-12	37	
10	P-11	38	
11	P-2	39	
12	P-1	40	
13	P-15	45	
14	**P-9**	**104**	$75 to $115
15	P-14	109	
16	P-13	169	$116 or more

(1) Ties between packages correspond to multiple ranks on the same row.

TABLE 3 Grouping by Fleet Size, Division Access, and Coverage

Active Fleet Size
Preliminary Estimates of Active Trolleybuses

below 50	50 to 100	above 100
P-9, P-13, P-16	P-2, P-3, P-4, P-5, P-7, P-10, P-11, P-12, P-14, P-15	P-1, P-6, P-8

Average Distance to Operating Division(s)

less than _ mile	_ to less than _ mile	_ to 1.0 mile	greater than 1.0 mile
P-2, P-3	P-1, P-11, P-16 P-10, P-12, P-14, P-15	P-4, P-5, P-6, P-9,	P-7, P-8, P-13

Coverage of Trolley Bus Network
(one-way route miles)

less than 25 miles	25 to less than 27 miles	27 to 30 miles	above 30 miles
P-16, P-2, P-13, P-4	P-5, P-7 P-10, P-11, P-15	P-3, P-8, P-12	P-1, P-6, P-9, P-14

assignment among two separate divisions because of capacity constraints and limited expansion potential at existing divisions. Package P-6, being much larger, would present more opportunities for shared nonrevenue wire segments than P-5 as defined. Those points show some of the trade-offs expected in expanding from one package to another rather than adding a different package altogether (no common lines).

The future opening of the Pico/San Vicente Red Line interim terminus on the Westside might also modify current ridership patterns along Lines 30/31. Some bus patrons bound for the LACBD and East Los Angeles might shift to the Red Line trains and away from the Line 30/31 trolleybus service. Yet the new feeder function of this east-west local line would most likely draw new riders to the same West Pico Boulevard segment proposed for electrification.

Package P-9

Package P-9, which consists of MTA Lines 70 and 92/93, was not recommended for the first phase, although the central portion of Lines 92/93 may need to be restudied at a later phase. This package ranked very low for the two quantitative indicators in Table 2. It ranked last for service intensity and third to last for cost-effectiveness. Since current base headways on Lines 92/93 to the north of Burbank are much longer than 15 min, truncating both lines in Burbank seemed consistent with the screening criteria. The spreading between the central San Gabriel Valley (Line j70 eastern terminus) and the north San Fernando Valley (Lines 92/93 northern terminus, if trolleybus were to run north of Burbank) brings too many operational disbenefits. The incremental cost of adding midday service on Line 410 outer leg is also counterproductive. As an added disbenefit for this package, long deadhead trips to and from the proposed shared operating division (adjacent to the LACBD legs of both routes) warrant partial conversions of two outer divisions to trolleybus storage.

Dropping a given package from the first phase does not always imply that another package, using some of its lines, might not be a candidate for near-term electrification. As indicated in Table 1, associating Line 70 (part of P-9 above) with Lines 30/31 (part of P-5 and P-6 above) makes a much stronger candidate P-10 than the P-9 combination. Per Table 2 results, P-10 ranked seventh in cost-effectiveness and tenth in service intensity. Package P-10 was indeed recommended for the first phase of the project.

CLUSTER CONCEPTS

One advantage of working with packages was to help frame the options for coach assignments to viable operating divisions. This is one aspect of the trolleybus program development in need of coordination with methanol-powered fleet expansion by MTA. Another advantage of evaluating packages (rather than focusing on individual lines) was to have a more manageable data set with which to deal. (Table 3 gives groupings that are based on fleet size, division access, and coverage.) The Electric Trolleybus Coordinating Committee also endorsed the approach of relying on unweighted criteria in summarizing the results and making recommendations. No predetermined "acceptable" range was set before the quantitative results were compiled among the various packages.

The overall evaluation did reflect the solid framework tied to the two quantitative measures, given in Table 2: the service intensity (i.e., vehicle service hours per route mile of line to be electrified) and the overall cost-effectiveness (relative to the air quality benefits over running methanol-powered coaches along the same paths and with comparable headways). As shown, there are few major ranking contrasts among these two primary indicators.

The definition of viable (numerical) clusters was then based on this unique set of packages. The authors could not recommend transferring those values to other systems, since such quantitative benchmarks depend on local operating practices. However, the same concept is valid for other transit agencies involved in an areawide review of candidate trolleybus corridors.

CONCLUSION

The evaluation approach used in Los Angeles proved to be a thorough and technically sound way to select the most viable corridor segments for near- to mid-term electrification. Although the impetus came from regional air control measures, some constraints to a fast-track implementation were indeed encountered. Such constraints are not expected to be unique to Los Angeles. They included the challenge of a fast-track vehicle procurement, when a limited market still exists for electric trolleybus fleet acquisition or development in North America, and the shortage of capital moneys to carry out the more attractive option of a full package instead of a partial one as a startup.

The trolleybus concept may not lend itself to support the rationale for a brand new service, for which local market demand has not yet been tested. This reinforces the original framework of focusing the first phase evaluation on local, nonfreeway lines carrying a stable ridership within the most densely traveled of the transit network. This is well worth emphasizing in view of the permanent location of overhead trolleybus revenue wire and associated facilities (power substations, nonrevenue wire to operating divisions). It also points to the relative merit of deploying alternative fuel-powered vehicles, such as methanol-powered coaches, in areas with emerging transit markets or likely changes in the coverage of their local transit lines—as often expected for corridors with programmed rail transit or express bus improvements.

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Electric Trolleybus Operation on Controlled-Access Highways

JACK W. BOORSE

More than 50 years ago transit operations planners recognized the opportunity to make use of freeways to expedite selected movements of their conventional (gasoline and diesel) buses. Other planners found the medians and margins of freeways to be useful rights of way for rail lines. Meanwhile, electric trolleybus operation has been confined almost entirely to local urban and suburban streets with slow-moving traffic and closely spaced intersections. Now, driven by concerns about air quality and replenishable fuel, there is a renewed interest in the trolleybus mode. Progressive planners are considering the feasibility of expanding the operating environment of the trolleybus beyond its traditional boundaries. One possibility is to operate trolleybuses on freeways in a manner similar to diesel buses. If operation on freeways and other controlled-access highways is to be seriously considered, a number of factors not present with local street operation must be explored. These factors are identified and discussed.

Most early North American electric trolleybus (ETB) lines replaced local streetcar lines, and as a result they were born into an operating environment that consisted of local urban and suburban streets with low traffic speeds and closely spaced intersections. The quality of service that they could provide in that environment made competition with the automobile difficult. Automobile traffic (and congestion) increased and the diesel bus became the predominant surface transit mode.

As the network of freeways and other controlled-access highways grew, many transit passengers began to drive their own cars to enjoy the benefits of these new time saving facilities. Obviously, the general effect of the new highways on transit was negative, although not totally so. In certain corridors diesel buses were able to use the new freeways to reduce travel time for their passengers and simultaneously lower operating costs. Meanwhile, the increasing automobile ownership produced higher traffic volume and greater congestion on the local streets where the majority of transit vehicles continued to operate.

A few of the surviving streetcar or trolley operations were able to avoid some of this congestion by using underground alignments or aboveground private rights of way. In those cities where trolley service has been restored, decades after it was abandoned, the new lines have made extensive use of private rights of way, including the medians and margins of freeways. Now generally known as light rail transit (LRT), the number of trolley systems more than doubled in the past 15 years and very likely will double again in the next 15 years.

In contrast ETB operation has continued to decline. In 1990 11 were operations left: 2 in Mexico, 5 in the United States, and 4 in Canada. Of those, only three—Seattle, San Francisco, and Vancouver—were robust. Now there is a renewed interest in the trolleybus mode, and thought is being given to ways that it too can benefit from more traffic-free environments. If LRT can operate in highway medians and diesel buses can run on freeways, why cannot ETB do the same?

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Operation in highway medians operation appears to be feasible for all three modes: LRT, ETB, and diesel bus. It is even possible that they could all use the same reserved right of way, but that is not the subject of this paper. What is explored here, and only in a preliminary manner, is the notion of operating trolleybuses in mixed traffic on freeways and similar facilities in the same manner that diesel buses now operate.

Before proceeding further, a word must be said about terminology. There is an inconsistency in the names for the various controlled-access highways resulting from colloquial usage. As an example, the portion of Interstate 676 situated in Pennsylvania is called an expressway whereas the contiguous portion of the same highway in New Jersey is called a freeway. A major freeway in downtown Pittsburgh is called a parkway.

The *Manual on Uniform Traffic Control Devices* (MUTCD) defines expressways as "divided arterial highways for through traffic with partial control of access and generally with grade separation at major intersections" (*1*). The MUTCD does not include a formal definition of freeways, but it does discuss them separately from expressways, very clearly indicating that the two facilities are not the same.

The *Highway Capacity Manual* (HCM) defines a freeway as "a multilane, divided highway having a minimum of two lanes for the exclusive use of traffic in each direction and full control of access and egress" (*2*). The HCM does not define expressway separately. It classifies all highways (including expressways) that have two or more lanes for each direction but lack full control of access simply as multilane highways.

In this paper all references to those two types of facilities are consistent with the definitions cited. These references are made without regard to the actual local names (such as parkway, shortway, tollway, throughway, turnpike, etc.) that highways of these two types might have.

FREEWAYS

When contemplating ETB operation on freeways, one must address operating speed. Virtually all freeways are designed for speeds of at least 81 km/hr (50 mph) with most designed for more than 110 km/hr. At present in urban areas, where ETBs would most likely operate, maximum speed limits are set at 89 km/hr (55 mph) in the United States. However, it is by no means certain that those limits will not be increased. So, if trolleybuses are to operate on these facilities they should be designed to run at speeds of at least 90 and possibly 105 km/hr (65 mph).

Fundamentally the ETB is a bus, and buses are already designed to travel at 110 km/hr. The only differences between the two vehicles are the source of mechanical power (electric motor versus internal combustion engine) and the need for the ETB to collect electrical current from overhead wires.

Looking first at mechanical power, electric motors already move passenger trains at more than 200 km/hr in the Northeast Corridor and much, much faster in Europe and Japan. The ability of an electric motor to move a trolleybus at 105 km/hr would appear to be without question.

Electrical current collection is a different matter. Virtually every ETB operation in the world uses a pair of roof-mounted poles topped by sliding, grooved collector shoes to connect the vehicles' motors electrically with the bottom side of a pair of contact wires suspended about 5.5 m above the surface of the road. Thus, it would appear that, by either design or circumstance, the ETB operating authorities around the world have adopted a de facto standard technology for collecting current. It is not likely that the basics of this time-tested technology will change soon unless a very cogent reason emerges. This does not preclude further refinement and improvement of its design.

This then leads to the question of the ability of this current collection system to function reliably at, or close to, 105 km/hr. In an attempt to answer this, it appears logical to look at another mode that has successfully collected power from an overhead trolley wire by means of a pole and sliding shoe at high speed, the once common interurban electric railway. ETB poles and collector shoes are very similar, but not identical, to those that were used by most interurban railway cars in the first half of this century and many of those cars operated at substantial speeds. As an example, those that ran between Chicago and Milwaukee routinely reached speeds in excess of 140 km/hr. Therefore, at first view, it would appear that current collection by trolley pole and shoe for 105-km/hr trolleybuses should be feasible, but that may not be so.

By the nature of its design a rail car follows a precise and absolutely predictable path (Figure 1, *left*). No skill on the part of the operator is required to achieve this. The horizontal angle between the pole and the contact wire at any given point along the line is always exactly the same, 0 degrees where the alignment is tangent and within a very few degrees of that on a curve. The collector shoe is designed to rotate in a vertical plane to accommodate varying wire height, but because its horizontal orientation to the wire is always essentially parallel, there is no need for it to rotate in a horizontal plane. Therefore, it is fixed in the same vertical plane as the pole to which it is attached.

On the other hand, an ETB does not follow a precise path (Figure 1, *right*). It is designed to operate up to about 4 m (nominally one traffic lane) to either side of the center of the overhead wires feeding it. To accommodate this, the collector shoes are not rigidly attached in either plane. They swivel not just in a vertical plane to accommodate varying wire height, but also in a horizontal plane so that the groove in the shoe can remain parallel with the wire even when the pole is not (Figure 2).

With both modes a special device must be incorporated into the overhead wiring at the junction of routes. This device, called a frog, serves two purposes. One is to connect mechanically the three wires, and the other is to guide each collector shoe from the wire on the route it is leaving to that of the route it is joining.

For rail cars the frog is a simple passive device. It is attached to the underside of the wires being joined and has grooves that act as a guideway for the top edge of the two sides of the collector shoe as it rides off of one wire and onto another. Because the shoe is locked in the same vertical plane as the pole, its edges are inherently aimed toward whichever set of grooves leads in the direction that the car is proceeding.

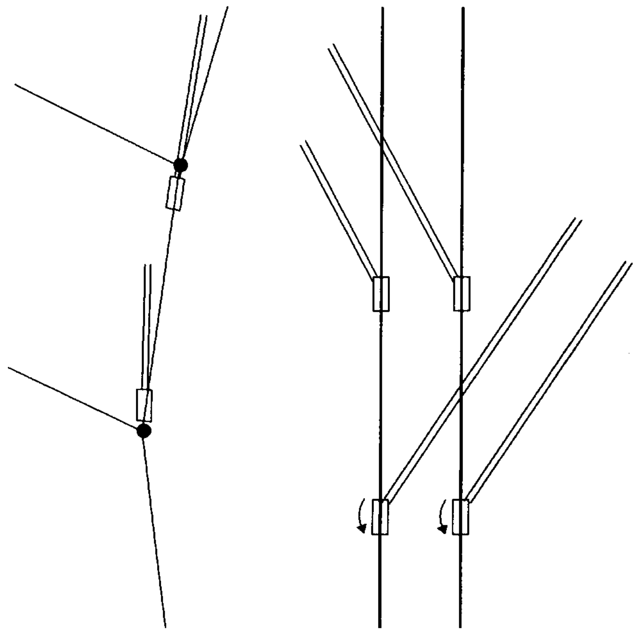

FIGURE 1 Angle between trolley pole and wire: *left*, rail car; *right*, trolleybus.

As a result of its ability to rotate horizontally, the collector shoe on an ETB is not automatically turned into a diverging path and will generally remain aimed straight ahead even when the pole to which it is attached begins to turn. Thus, the passive rail car–type frog is not usable. A trolleybus frog is an active device in which a guide bar is rotated by a solenoid or motor to direct the shoe onto the correct wire. To minimize the size and weight of the frog the length of this bar is kept short. This necessitates a significant angular difference between the two positions and that requires very slow operation of the shoe through the frog when it is set in the diverging position. A redesign of the frog perhaps using much longer guide bars to permit a higher linear shoe speed is a possibility. Reportedly, prototype hardware has been developed in Europe to accommodate collector shoe speeds of up to 80 km/hr. However, in its present North American form an ETB diverging from a freeway lane would have to slow to as low as 30 km/hr to avoid dewirement. In a traffic stream moving at just under 90 km/hr this would be hazardous.

Even on plain wire the dynamics of current collection of the two modes is different. An ETB collector shoe would have a

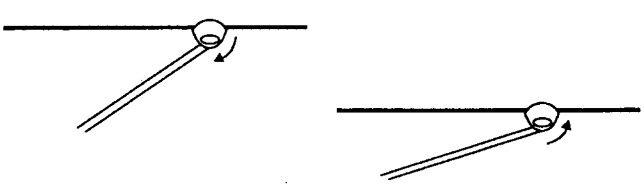

FIGURE 2 Vertical angle between trolley pole and wire.

greater tendency to dewire than that of a rail car at any given speed. Whenever the body of a moving trolleybus is not directly under the center of the wires, the angular forward force from the pole and the rearward parallel force from the friction of shoe-against-wire creates a lateral force component. This force increases with speed, and as it increases so does the tendency for the shoe to dewire. The lack of rigid fixation may also allow the shoe to exhibit some angular vibration in the horizontal plane.

The tendency to dewire would be further increased whenever an ETB driver might find it necessary to swerve suddenly to avoid a collision. The resulting lateral forces could both be increased with freeway operation as compared with local street operation because of the higher speeds. Finally, the probability of dewirement of an ETB compared with a rail car is worsened by the fact that the former has twice as many poles per unit as the latter, doubling the statistical probability of a disabling dewirement. Even if one pole remains on the wire, the flow of current from the overhead wires will still stop.

Thus, on the matter of ETB operation at freeway speeds, the successful experience with high-speed trolley pole current collection by rail vehicles should be studied for ETB application. Perhaps the use of catenary rather than direct suspension trolley wires should be considered. However, at this time the rail car experience should not be taken as conclusive proof that trolleybuses can operate at comparable speeds. Higher ETB operating speeds are potentially feasible, but considerable research and development will be needed to achieve it.

The next matter to be considered is the effect of dewirements. Measures such as limiting vehicle speed and designing an overhead contact system to tolerate higher current collector speeds address the avoidance of dewirements. But it would be as fallacious to assume that a trolleybus would never dewire as it would be to assume that an internal combustion engine would never run out of fuel or otherwise fail. The problem of dewirements on a freeway must be fully considered.

A design feature that would help address this problem is the addition of an auxiliary power unit (APU) to ETBs assigned to freeway service. An APU can be a battery or a small internal combustion engine coupled to a generator. Traditionally, ETBs have not been provided with APUs, but for freeway operation the capability to move after a dewirement could avoid some serious safety problems.

To rewire an ETB at any location, each collector shoe must be moved under its respective wire and then raised. Rewiring can be accomplished from within the vehicle, but to do so it must be positioned directly below the wires at a point where basket-like devices have been installed to catch the top of each pole and guide its shoe accurately into proper contact (Figure 3). If the rewiring is done manually, catch baskets are not needed and the body of the vehicle need not be directly under the wires, but the person manipulating the pole and shoe must be (Figure 4). Obviously, in the case of an unanticipated dewirement on a freeway, manual rewiring would be necessary.

A likely procedure would be to have the driver coast or engage the APU to drive the vehicle onto the shoulder of the freeway and await assistance. Then, under the protection of a police car or other vehicle with appropriate warning devices, the driver would drive the ETB back out into the closest freeway lane with wires, stop, raise the poles manually, disengage the APU, and resume service.

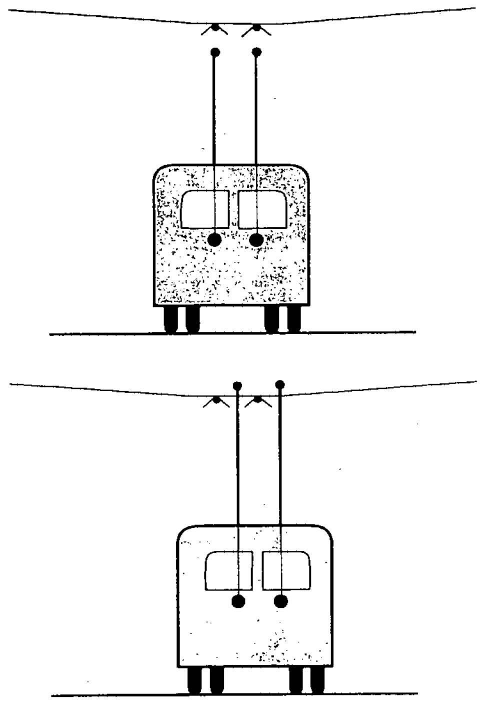

FIGURE 3 Positioning of bus for catch-baskets.

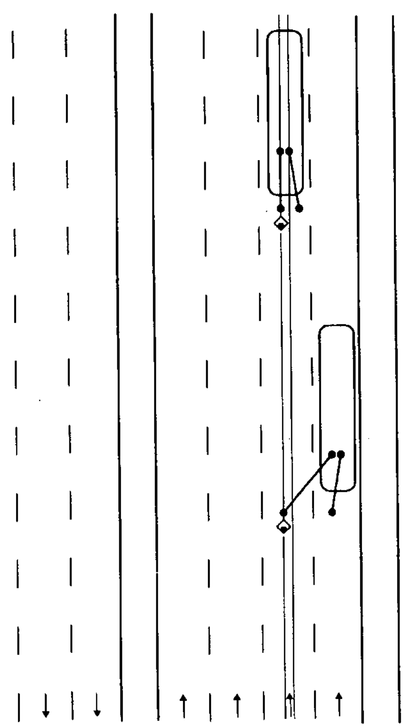

FIGURE 4 Driver standing positions for manual rewiring.

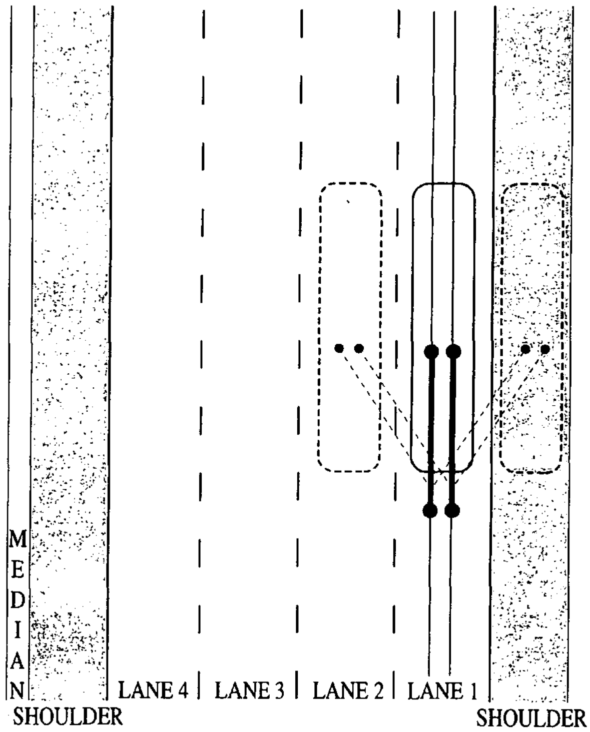

FIGURE 5 Travel lane options: wires over right lane.

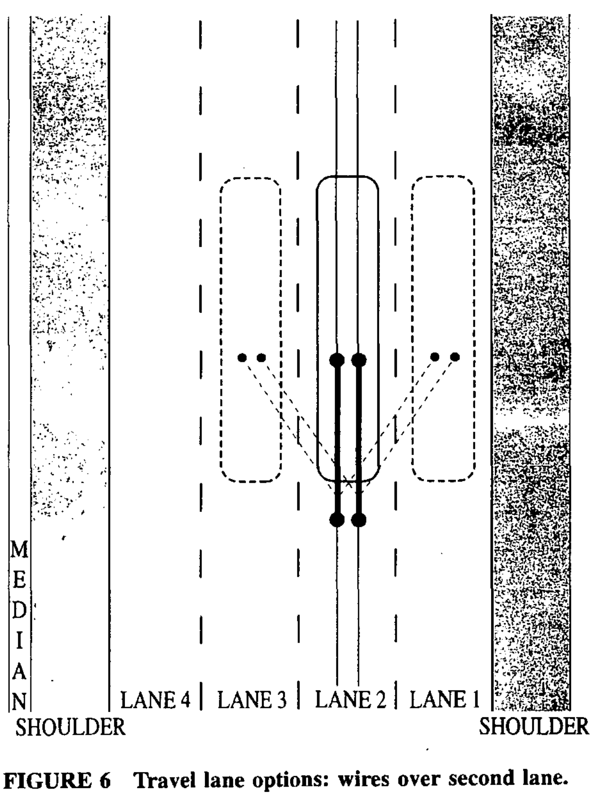

FIGURE 6 Travel lane options: wires over second lane.

Another matter that must be addressed is the positioning of the wires over freeway lanes (Figures 5 and 6). The ETB is designed to operate in the lane over which the wires are placed and in the immediately adjacent lane to the right or to the left of that lane. Traffic lane widths on urban streets are usually in the range of 3 to 3.5 m. On freeways they are 3.65 to 4 m. The additional lateral deviation required by the wider lanes can be mitigated, at least to some extent, by using longer current collection poles. However, there is no apparent possibility of providing for a two-lane deviation from the lane over which the wires are positioned.

For safety reasons a failing trolleybus should have the same access to the shoulder of the freeway as any other vehicle. For a traditional ETB this means that because of the lateral limitations described earlier, the wires must be placed over the extreme right-hand operating lane. As a result, ETB operations on a freeway would have to be limited to the two traffic lanes closest to the shoulder, regardless of how many might actually exist for each direction of traffic flow. From a transit operations viewpoint this restraint is not desirable, but it probably is not serious and certainly not a fatal flaw. However, if all ETBs assigned to freeway routes carry an APU, the immediate proximity of the wires to the shoulder is no longer essential.

The presence of the wires would have several potential adverse effects on other freeway operations, particularly those of high vehicles (Figure 7). The highest vehicle that would likely be permitted on a freeway without a special permit is a double-deck bus with a height of about 4.42 m (14.5 ft). The highest truck should not exceed 4.12 m (13.5 ft). Vehicles of both types could easily pass beneath trolleybus contact wires that are 5.5 m above the road surface. Any span wires or mast arms supporting them would be even higher and so, in theory, the wiring would not create a vertical clearance problem. In practice there could be some problems.

A potential problem would exist if a trolleybus, while operating in the second lane from the right, was overtaken by or overtook a high truck or double-deck bus in the extreme right lane. Since the wires, of necessity, would be over the right-hand lane, the poles on the trolleybus would be ''reaching'' to the right to follow them. Depending on where (laterally) in their respective lanes the ETB and the high vehicle were, the poles of the former could come into physical contact with the latter. In that situation a dewirement would be virtually unavoidable.

Another factor to be considered is that, in practice, freeways also accommodate overheight loads. Although such movements require advance notice and special permission, possibly including an escort, none of these procedures can circumvent the laws of physics. Overheight loads in excess of about 5.4 m (17 ft 9 in.) would not be able to cross under the ETB wires. Therefore, when entering or leaving the freeway, such loads would be unable to use any ramp that would require passage under the wires (Figures 8 and 9). In extraordinary circumstances (and provided that catenary was not used) those wires could be temporarily raised or severed and reconnected by maintenance forces to allow passage of the overheight load. Needless to say, in those circumstances ETB operation would have to be suspended until the wires were returned to their normal position. Such a service suspension would constitute a major inconvenience to the transit passengers.

Obviously, the occasional movement of an overheight vehicle should not dictate the design of a public transit facility. On the other hand the need to move overheight vehicles on a freeway system from time to time cannot be disregarded. The potential

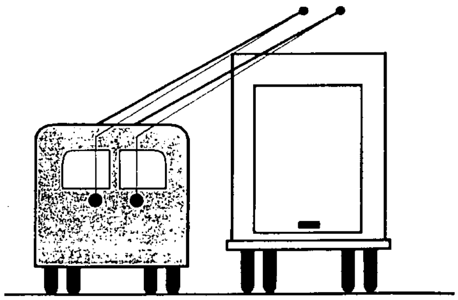

FIGURE 7 Potential physical conflict: high truck in travel lane under wires.

interface of overheight vehicle and ETB operation must be taken into consideration.

These may not be insurmountable problems. Lowering the poles and exiting (but not entering) under APU power might be feasible. If so, the wires at some of the problematic locations could be deleted. Obviously, full and careful consideration will be required when designing the wires at these sensitive locations.

EXPRESSWAYS

Expressways have many characteristics in common with freeways. Obviously, all of the foregoing observations and comments that relate to those common characteristics also apply to ETB operation on expressways and need not be repeated. The following comments address those elements that are not relevant to ETB operation on freeways.

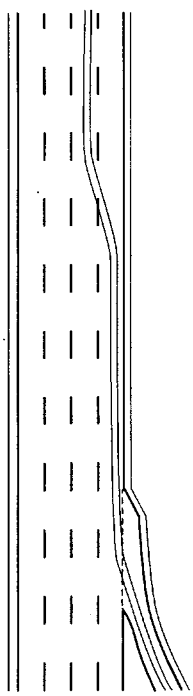

FIGURE 8 Wire configuration, on-ramp from right.

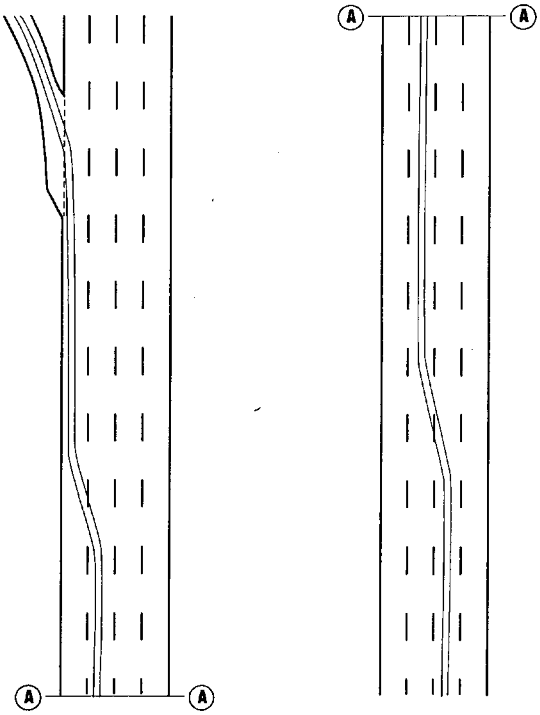

FIGURE 9 Wire configuration, off-ramp to left.

Probably the biggest difference between freeways and expressways is that the latter have some at-grade intersections. These intersections are not universally signalized, although commonly they are. When designing a new expressway ETB operation, if a routing onto or off of an expressway can be at an intersection under signal control rather than at a ramp interchange some of the potential problems associated with ramps discussed earlier would be avoided. However, if that would require an overall routing significantly inferior to one that would involve entering and leaving the expressway via ramps, it might be preferable to accept the effects of the ramp option.

Certain expressway interchanges are partially grade separated, with some of the through lanes overpassing or underpassing the intersecting street and others crossing at grade. Generally these are accompanied by slip ramps in advance and beyond to allow traffic to move between the grade separated "express" lanes and the "local" lanes that cross intersecting streets at grade.

An expressway ETB line having no need to enter or exit at such an interchange could be routed along either set of lanes. Selecting the at-grade lanes would offer the opportunity to provide a passenger stop. It would also provide a potential connection to a future intersecting trolleybus line. Selecting the grade-separated lanes would bypass the traffic signals and avoid delay. However, since the wires probably would initially lead into and eventually lead from the local lanes, this would require that they be routed through the slip ramps. The incremental time saving of that routing would have to be weighed against the problems generated by weaving across the local lanes, through a slip ramp, then back through another slip ramp and back across the local lanes. The disadvantages of using the grade-separated lanes of an expressway could outweigh the advantages.

SUMMARY

When the electric trolleybus first appeared in the 1920s there was no such thing as a freeway. Today, seven decades later, these marvels of roadway engineering are an integral part of the street and highway system of virtually every North American city. Freeways will be with us for a long time.

Now, there is renewed interest in the electric trolleybus as an urban transit mode. How large a role it will play remains to be seen. Certainly its chances will be enhanced if new applications are considered. Operation on freeways (and also expressways and parkways) is one of those applications.

The foregoing, as indicated at the outset, is not an in-depth study of the ramifications of freeway trolleybus operation. Neither is it, nor was it intended to be, conclusive. It identifies some serious concerns but finds no generalized fatal flaws.

At a minimum, current collection equipment must be perfected or redesigned to accommodate higher operating speeds and practical APUs need to be developed. More detailed studies are needed and demonstration installations on a test roadway or even on actual freeways should be considered as an inescapable element of those studies. Much work lies ahead.

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Publication of this paper sponsored by Committee on Bus Transit Systems.

Wire Requirements for Trolleybus Systems

ARTHUR SCHWARTZ

Changes in route structure needed to develop a group of high-density trolleybus routes in a medium-sized transit system are examined. The subject areas include treatment of branches and route extensions, route changes to maximize wire utilization, and modifications of pairings in a through route structure centered on a downtown transfer point. Wire is rarely provided for express or limited-stop operation. Where such service is a sizable component of a route, wire may be justified. An example of the treatment of such a route in New York is described. The need to provide wire for infrequently used movements has become a subject of question in two situations: where service is scheduled but consists of only a few trips per day, generally in late evening or early morning hours; and where service is not regularly scheduled but a route is used on a regular basis to turn back late buses or as a detour for frequently occurring special events.

This paper describes the changes in route structure needed to develop a group of high-density trolleybus routes in a medium-sized transit system, the development of wire alternatives for limited-stop and local service on a high-density route, and the decision process for installation of relatively infrequently used wire in two situations.

In one case, Long Beach Transit (LBT), the four routes had been selected as candidates for trolleybus operation because they met the requirements of having a 15-min or better peak headway over a substantial part of the route and of having substantial route overlap. The effort to be described was intended to restructure the selected routes in order to increase the use of the trolleybus fixed plant.

In the other two cases, it had been decided that the entire routes were to be considered for trolleybus operation. This paper covers an evaluation of the amount and location of wire needed to provide trolleybus service equivalent to the existing diesel bus service.

ROUTE STRUCTURE CHANGES FOR TROLLEYBUS CONVERSION

This section describes the planning performed by LBT to develop a route package for inclusion in the trolleybus program developed by the Los Angeles County Metropolitan Transit Authority (LACMTA).

LBT operates a bus system with 17 routes serving the city of Long Beach, California, and surrounding communities. Downtown Long Beach is approximately 20 mi south of downtown Los Angeles. Although it is in the southwest part of the LBT service area, it is the center of LBT service, being served by 13 of the 17 routes.

The four routes selected for examination are shown in Figure 1. These routes all serve the area north and east of Downtown Long Beach. Figure 1 shows the current layout of the four routes as well as the route segments proposed for trolley and diesel bus operation. Each route is discussed in detail in the following paragraphs.

The 40 route consists of two branches, each with 30-min headway throughout the day, on Magnolia and Pacific Avenues. These combine at the downtown loop to provide 15-min headway on Anaheim Street. Alternate trips (30-min headway) are extended to the east of the primary terminal on Anaheim Street to provide service to California State University, Long Beach (CSULB), and an area east of the university. A supplemental service, crosstown route 45, operates on a 15-min headway along Anaheim Street during peak periods, providing additional service on the most heavily used portion of the route as well as a shorter path between the ends of the route.

This route required substantial restructuring. The branches on Pacific and Magnolia Avenues are separated into a new diesel bus route. The east extension is swapped with another route to move it from a residential to an arterial street and to position it to share wire with the 90 route to a proposed major transfer point. The easternmost end of the route is discontinued, being replaced by a combination of currently operated duplicate service and by the rerouting of a diesel bus route. The supplemental crosstown route 45 is unchanged except that it will be shortened about 1 mi on the west end to avoid the need for wire in an area of very low usage where duplicate service is available.

The resulting trolleybus route will consist mostly of segments with an average peak-period headway of $7^1/_2$ min, resulting either from the combination of the 40 and 45 routes or from joint wire use between the 40 and other routes. The exceptions are $^1/_2$ mi of wire on the west end of the 45, which will have 15-min headway and $^3/_4$ mi of wire east of the main terminal that will have a 30-min headway. This section is also needed for garage access to the east end of the 90 route.

The 50 route on Long Beach Boulevard north of the downtown loop operates at a 15-min headway throughout the day. East of downtown on Fourth Street, every other bus turns back at a point about halfway on the route, thus providing a 15-min headway on the inner end and 30-min headway on the outer end. Because of this cutback, the east end of the route has insufficient service density to justify trolleybus conversion.

The 50 route will thus be split, with the portion north of downtown being converted to trolleybus while the portion east of downtown is through routed with the new diesel bus route that will serve Magnolia and Pacific Avenues now on branches of the 40 route. The wire on the 50 route will thus be used every 15 min throughout the day except where it is shared with the 40 and 60 routes.

The 60 route on Atlantic Avenue will be largely unchanged. Now the route operates on a 10-min headway during peak periods and a 15-min headway in the midday with alternate trips serving two branches at the north end; it is not through routed in the

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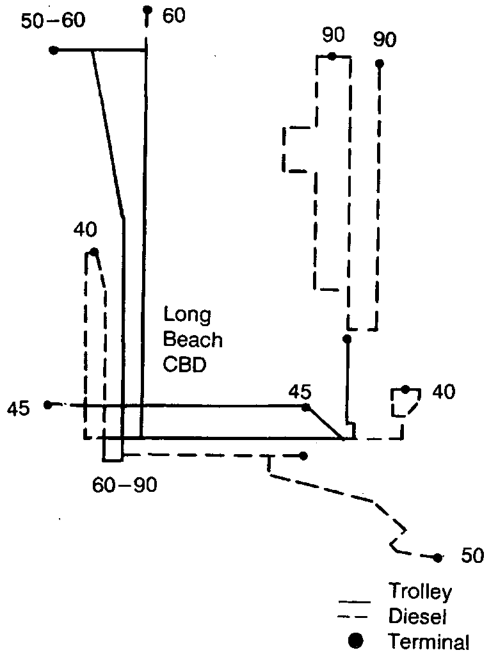

FIGURE 1 Routes considered for electrification, LBT.

downtown. One branch, about 1 mi long, will be abandoned. Two LACMTA routes also provide service to the area served by this branch. All service will be relocated to the other branch, which feeds a Blue Line rail station and shares some wire with the 50 route.

The 90 route on Seventh Street and Bellflower Boulevard currently has three branches. Headway on the trunk route is 10 min during peak periods and 12 min in the midday. Branch headways are 30 min on the Woodruff Avenue branch and 60 min on the other two branches throughout the day. A 5-min headway is provided on the trunk portion of the route during a portion of the a.m. peak on days when school service is operated.

The route is proposed to be split, with the trunk route being converted to trolleybuses and the three branches being replaced by diesel bus shuttles. At present, short-turn buses serving only the trunk route terminate about $^1/_2$ mi short of the point at which the first branch diverges. This latter point is proposed to be the new transfer point for the service. One change to the branch structure is the operation of the two branches having 60-min headways as a two-way loop, so that a round trip can be made in 1 hr.

A change may be made to the trunk route at CSULB. The present route through the campus may not be retained if CSULB does not agree to install wire on it. If this route is moved to Bellflower Boulevard, the internal campus shuttle bus service will have to be expanded as a replacement.

One factor that improves the efficiency of the proposed route changes is the layout of the downtown loop. It is short, being designed primarily to route all buses past a common transfer point. Splitting a through route adds only about $^1/_4$ mi of distance to each leg. Thus, the advantage of through routing is primarily to match headways and running times, which is much more important on routes with infrequent service than for routes with frequent service such as the proposed trolleybus routes. In addition, LBT has recently revised its schedules to move all layover time to the outer ends of routes. Thus there is no layover penalty in splitting through routes.

Figure 2 shows a wire schematic of the proposed trolley coach system. It should be noted that the only nonrevenue wire in the proposed route structure is the garage entrance and the turns at Atlantic Boulevard and Anaheim Street that are needed to provide a route between the garage and the north end of the 50 and 60 routes. At present, a right turn from westbound Anaheim Street to northbound Long Beach Boulevard is made by two early morning trips. One of these trips is needed to provide early morning Blue Line feeder service, and it was decided that it was uneconomical to provide switches for the turn for just one trip. This trip will thus have to make the turn on battery power or be rerouted to start at the downtown loop and start about 20 min earlier.

The proposed trolleybus system is estimated to require 37 vehicles to provide the current level of peak service. The diesel bus routes that serve segments that will not be equipped with wire are estimated to require 12 vehicles for peak service. Thus, 76 percent of the service on the restructured system is provided with trolleybuses. Only a $^3/_4$-mi segment of the trolleybus system fails to meet the goal of a 15-min peak headway, as compared with approximately 29 route-mi of the four selected routes before restructuring.

EXPRESS OR LIMITED-STOP OPERATION

As part of a study of the feasibility of converting the M15 route to trolleybuses, approaches to providing both local and limited-stop service on this route with trolleybuses were examined. This route is operated by the New York City Transit Authority (NYCTA) and primarily serves First and Second Avenues in Manhattan. It is one of the three most heavily used transit routes in the United States. Limited-stop service is currently offered on the portion of the route on First and Second Avenues north of Houston Street.

The decision to operate both local and limited-stop service with trolleybuses was based primarily on the amount of limited service, which is much more frequent than on most such routes. There are 210 weekday limited trips, which is more service than is operated on most transit routes. Another reason is that local and limited service is scheduled as one route, and operating costs would increase if the services were scheduled separately.

There are several alternatives for the wire layout on First and Second Avenues north of Houston Street. These include

- A single pair of wires in each direction,
- A single pair of wires in each direction with periodic passing segments,
- A double pair of wires in each direction with separate wire for local and limited service, and
- A double pair of wires in each direction with crossovers between wires so that local and limited service can use either wire.

The single-wire pair alternative was rejected because it is incapable of supporting the existing limited/local service pattern. As shown in Figure 3, limited buses are scheduled to pass five to seven local buses on Second Avenue during the morning peak. It would be feasible only if local service is operated with trolley coaches and limited service with diesel buses, or if limited service is eliminated.

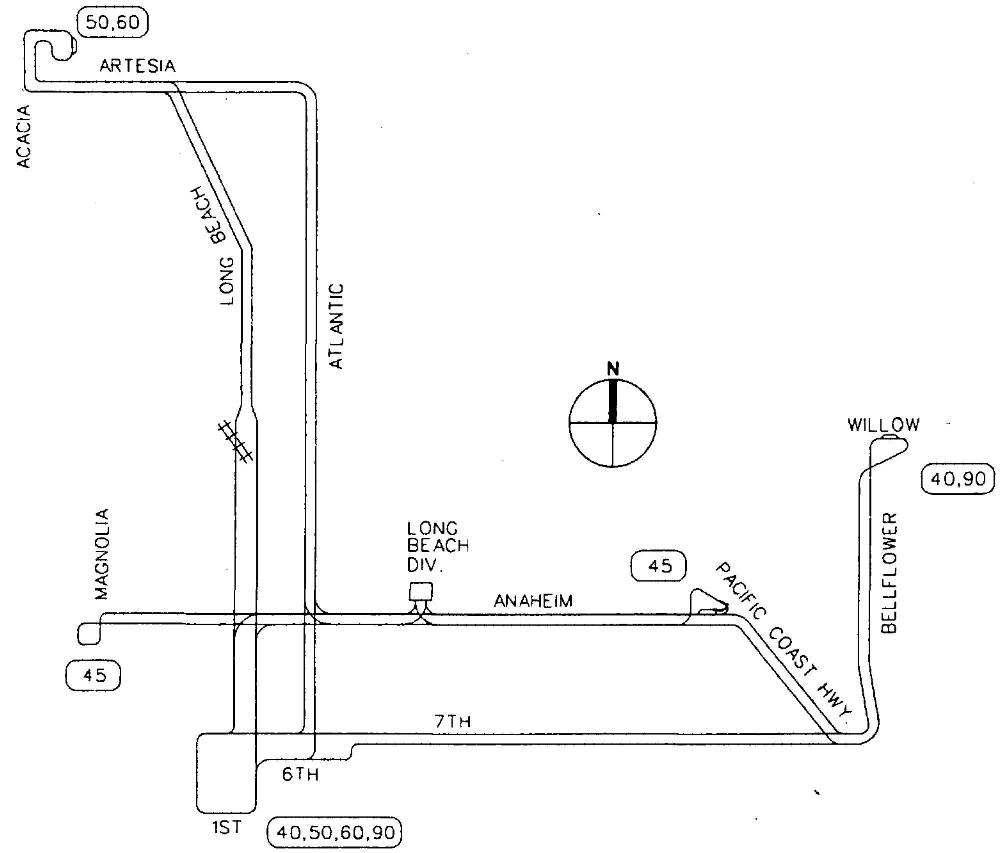

FIGURE 2 Proposed wire map, LBT.

The alternative of a single-wire pair with passing segments was rejected because of the high costs of installation and maintenance. Passing segments would need to be installed at about $^1/_4$-mi spacing to come close to replicating the existing service pattern. The running time of limited service would still be somewhat longer than would be possible with double wire. The initial cost of the 24 to 25 passing segments that would be needed to provide $^1/_2$-mi spacing is likely to be as much as four times higher than the cost of double wire. In addition, maintenance requirements would be substantially increased and the system would be much more visually intrusive. Driver workload would increase because of the need to be aware of the location of many switches and the need to operate these switches on the basis of an observation of the preceding buses in the traffic stream.

The double-wire pair alternative was selected. It preserves the present limited/local service pattern with almost no effect on service. It is reasonably straightforward to design and construct, requiring special work only at the ends of the double-wire pair sections on First and Second Avenues and at turnback locations. There is a minor problem with this alternative in that although limited buses can pass local buses, neither local nor limited buses can pass another bus in the same service.

The alternative of a double-wire pair with crossovers was rejected because of the same cost and driver workload disadvantages described in the passing segment alternative. In fact, it would be substantially more costly and complex than the passing segment alternative. Each passing point requires four to six switches as compared with two for the previous alternative. Its only benefit is that it provides somewhat more operating flexibility than the double-wire pair without crossovers.

As part of the development of the double-wire pair alternative, it was necessary to determine wire placement both for the double-wire section on First and Second Avenues. The limited/local operation currently in service on First and Second Avenues is different from existing double-wire pair trolley coach operations in that all buses use curb stops. There are three options for placing the double wire on First and Second Avenues, two of which retain the curb stops. The options are

- Placing both local and limited wire in the second traffic lane. The local wire is centered 12 ft from the curb; the limited wire is centered 16 ft from the curb. This option has the advantage of being the least expensive to install if bracket arms are used. The major disadvantage is the reduction in flexibility of lane use and difficult operating conditions resulting from this scheme. Limited buses will be operating near the maximum feasible touring range at bus stops and will be unable to use the fourth traffic lane. Local buses will be near the maximum touring range when operating in the third traffic lane and may have difficulty moving to the left side of this lane to pass a large vehicle. In addition, the close wire spacing is likely to result in trolley poles' being placed on the wrong wire after a dewirement, with subsequent damage to poles and wire. This scheme was rejected because of its unsuitability to traffic conditions.
- Placing the local wire in the second traffic lane and the limited wire in the third traffic lane, with the limited wire being

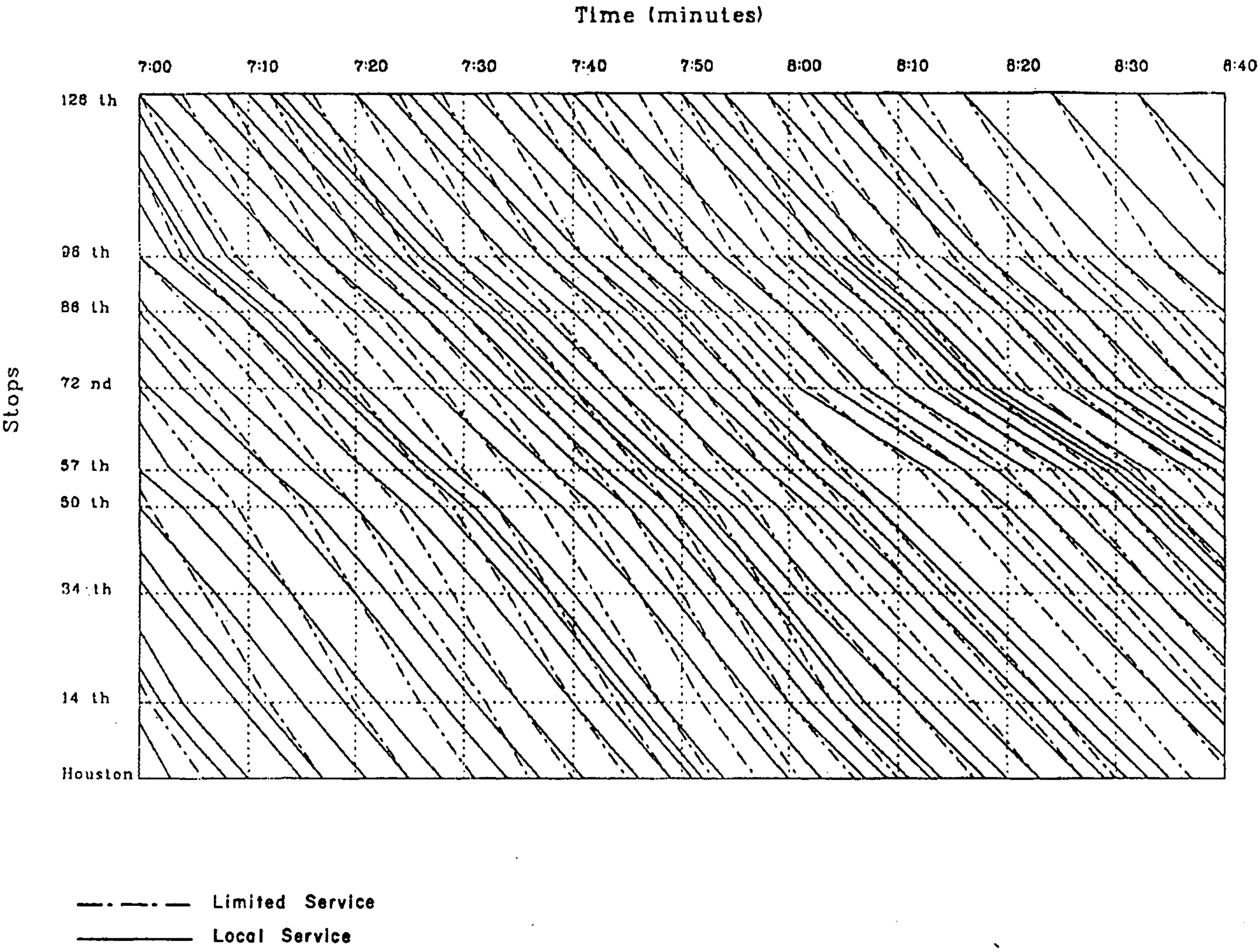

FIGURE 3 A.M. peak service density service diagram layout landscape, NYCTA Route M15.

located closer to the curb at limited stops. The local wire is centered 15 ft from the curb and is moved to 11 ft from the curb at limited stops; the limited wire is centered 26 ft from the curb and is moved to 15 ft from the curb at limited stops. It is necessary to shift the location of the local wire at limited stops in order to bring the limited wire to a position at which a bus can stop at the curb. Angular deflection is limited to 7 degrees at the shift points to minimize the effect on bus speed. This scheme provides adequate flexibility for local buses, which can operate in Lanes 1 through 3, as well as limited buses, which can operate in Lanes 2 through 4 except at limited stops. Disadvantages are that if bracket arm construction is used, the long arms are more costly and visually massive and that there is a small increase in cost and visual clutter due to the additional hardware and pulloffs needed to shift the wire at limited bus stops. This was the accepted option.

- Placing the local wire in the second traffic lane and the limited wire in the third traffic lane, with limited stops being made at traffic islands. The local wire is centered 15 ft from the curb; the limited wire is centered 26 ft from the curb. This option has the flexibility advantages of the previous scheme and would reduce passenger congestion at limited stops. It would be necessary to stagger local and limited stops at opposite sides of a cross street to avoid parallel stopped buses from impeding street traffic. The disadvantages of this scheme include the fact that the stop islands may be an unacceptable street traffic obstacle although adjustments in lane widths and shallow curb cuts could be used to avoid the loss of a traffic lane in most locations. In addition, the separation of local and limited stops is likely to be a problem for waiting passengers, because many are planning to take whichever bus arrives first. This option was rejected because of these two disadvantages.

Figure 4 shows the proposed wire layout for the M15 route including scheduled and unscheduled turnbacks.

REQUIREMENTS FOR INFREQUENTLY USED WIRE

Since some level of auxiliary power unit (APU) capability has become a standard feature in the specifications for new trolleybus

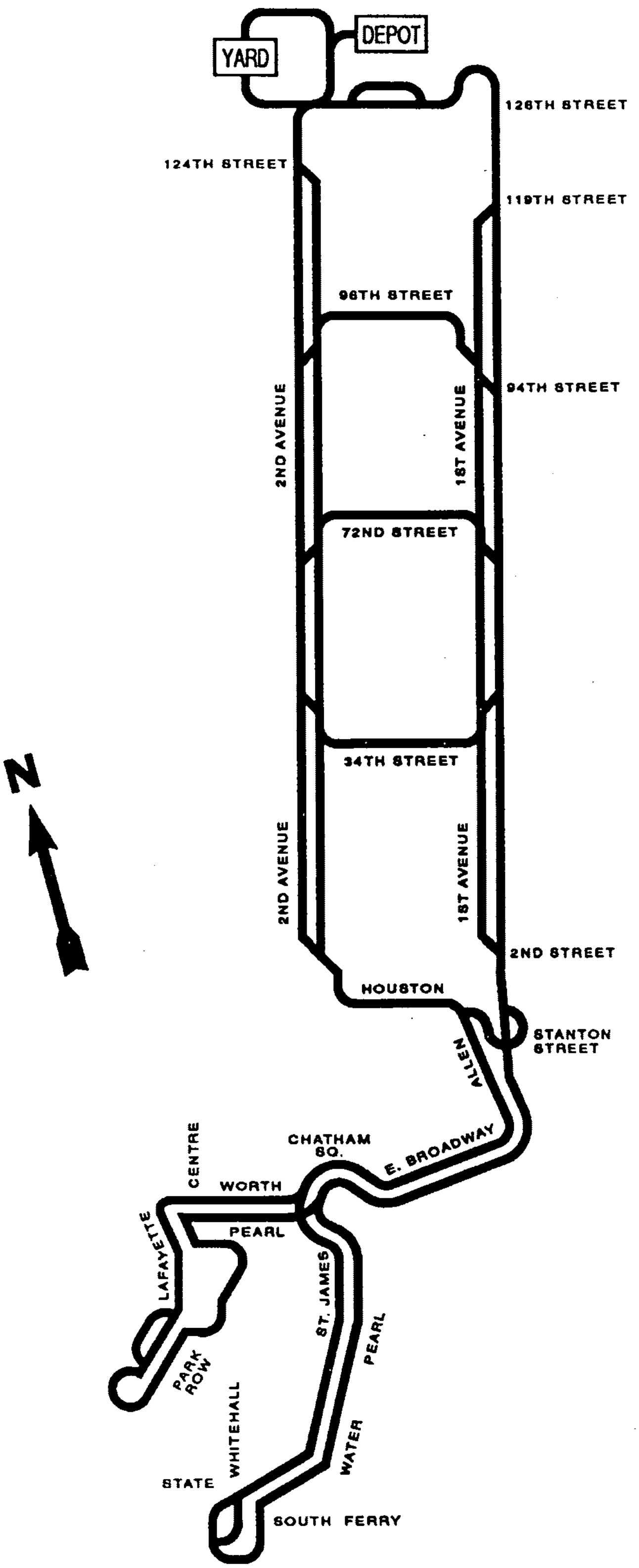

FIGURE 4 Wire layout for local and limited service, NYCTA Route M15.

systems, the need to provide wire for infrequently used movements has become an issue in the development of trolleybus routes. In this section, this issue is examined in two contexts: the need for wire to accommodate unscheduled but regularly used turnbacks and the need for a large number of scheduled turnback points.

The first issue will be examined in the context of a very high density route, the M15 in Manhattan. As can be seen in Figure 4, this route has four turnbacks. The two at 96th and Houston Streets are frequently used in scheduled service, with 82 and 107 weekday trips respectively. The turnbacks at 72nd and 34th Streets are not used in scheduled service. The NYCTA requested these turnbacks in order to provide a convenient means of turning back buses that are running substantially behind schedule on either side of the most heavily used and most congested part of the route in midtown Manhattan. Wired turnbacks were desired in these locations because (a) they are expected to be used on a regular basis, (b) traffic conditions in these locations make manual pole raising difficult and hazardous, and (c) the speed restriction and time used for pole handling inherent in the use of the APU are serious impediments to use of these turnbacks as a means of rapidly responding to minor service interruptions and delays.

The issue of whether to wire intermediate turnbacks is typified by the 66/67 route of the LACMTA. This route is shown in Figure 5. This route has six intermediate turnbacks and APUs will be used. Their location and use are shown in the following:

- Western Avenue: 87 weekday trips, all weekend service;
- Figueroa Street (Francisco Street): one daily trip;
- Boyle Avenue/Soto Street: 38 weekday trips, 9 Saturday trips;
- Mirasol Street (Calzona Street): shown in route description, not used in current schedule;
- Eastern Avenue: 31 Saturday trips, 23 Sunday trips; and
- Atlantic Boulevard: 38 weekday trips, 1 weekend trip.

The turnback at Mirasol Street is not needed, because it is not currently in use. The turnback at Figueroa Street is used by one trip at the end of the service day. It is likely that rescheduling this trip would be more cost-effective than installing wire, if the operating department does not want to use the APU in regular service. The turnbacks at Western Avenue and Boyle Avenue/Soto Street are used enough to be included in any wire plan. The turnbacks at Atlantic Boulevard and Eastern Avenue seem to serve the same purpose, turning alternate midday trips, on different days of the week. These turnbacks are only 1 mi and 4 min running time apart, and it is likely that only one of them is needed. Thus, it appears that the number of turnbacks can be reduced from six

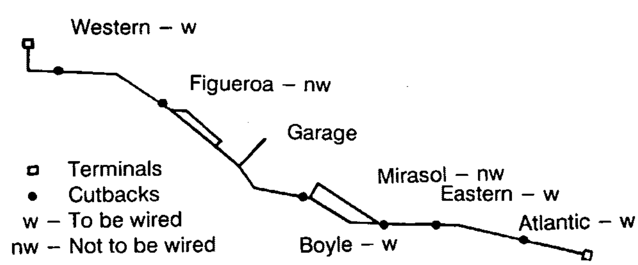

FIGURE 5 Turnback wiring requirements, LACMTA Route 66/67 East Olympic.

to three without significantly affecting service. The need to use these cutbacks for emergency service can be accommodated by using the APUs, which greatly increase operational flexibility in such situations.

The LACMTA project also analyzed the amount of wire needed in a garage location for a trolleybus system in which all vehicles are equipped with APUs. Four alternatives were developed:

- Installing wire from the garage entrance to the pole inspection location, in the parking lanes, and for all exit movements from the parking area;
- Installing a complete circulation loop through the garage property, in addition to the wire in the previous alternative;
- Adding wire through the bus cleaning facilities and switches to permit entrance to the parking lanes under wire; and
- Fully wiring the garage area, including access to the maintenance bays.

It has been decided that the complete circulation loop will be included in the garage wiring plan. Although it is not needed for normal garage operation, it provides a way to clear the main aisle in case of an APU failure as well as a place to test buses. It has not been decided if the additional wire through the bus cleaning facilities and the parking area entrance switches will be built. There is some feeling that this wire will decrease the time needed to service and park buses and thus reduce queueing of buses in the servicing process. There appears not to be any need for wire to access the maintenance bays.

It should be noted that LACMTA plans to use a battery APU. However, it is likely that the same considerations would apply to any type of APU system. For example, the higher speed that is achieved by an engine-driven APU is balanced by the time needed to start the engine as well as the additional servicing time.

CONCLUSIONS

There is no one answer to the question of how much wire is needed for a particular trolleybus system. In fact, this question will take a substantially different form in various situations. In one situation, the question may be how to restructure routes to create a system with enough service density to justify wire installation. In another situation, the question may be how much wire in addition to the basic route structure is needed to make the service function effectively. In a third situation, the question may be whether all of the route variations currently in use are really needed.

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PART 3

Rail

Regional Rail for U.S. Metropolitan Areas: Concept and Applications

JOHN W. SCHUMANN AND S. DAVID PHRANER

With old rail systems largely rebuilt and several new-start projects in revenue service, it is timely to discuss the idea of regional rail as a service concept, its historical evolution, and how it uses traditional rail "modal" technologies—heavy rail, light rail, commuter rail—as the basis for creating coordinated, multidestinational metropolitan transit systems. Regional rail is defined as "an emerging rail transit service concept and institution superimposed on a metropolitan region, employing conventional rail technologies, incorporating elements of older rail operations and infrastructure where they exist, and adding new links where required to integrate suburban, urban and downtown travel functions." It is suggested that regional rail distributes riders like rapid transit or light rail in the central business district, while providing express line-haul transportation like commuter rail between central cities and their suburbs. Thus, regional rail can respond well to the long trips characteristic of U.S. metropolitan areas. The place of regional rail in the phasing over time of transit system development is discussed, as are its general characteristics, organizing principles, and several examples. Finally, regional rail is seen as an opportunity to implement new operating practices and reforms, to investigate and apply technical innovations selectively, to control costs while attracting new customers from markets that street transit finds difficult to penetrate, and to offer a concept that managers can use to coordinate a range of integrated, high-quality transit services that can be sold across a spectrum of the traveling public.

Heavy rail, light rail, commuter rail: planners and engineers have been promoting and building these rail transit technologies for quite some time. Now that old rail systems are largely rebuilt and several new-start projects are in revenue service, professionals find themselves increasingly thinking less of these specific technologies and more about a fast-emerging service concept: regional rail. This paper discusses the idea of regional rail, its historical evolution, and how it uses traditional rail "modal" technologies to create coordinated metropolitan express transit systems.

U.S. RAIL TRANSIT PROGRESS IN THE FREEWAY ERA

Despite Americans' long-running, policy-supported, and publicly funded mania for automobiles, freeways, and low-density development, rail transit systems soon will serve more than half of the 39 U.S. conurbations that house more than 1 million people (Figure 1). Where they survived the mass rail abandonments of the mid-20th century, older rail systems have been renewed, and a dozen U.S. cities—many in the Sunbelt—have opened one or more completely new rail lines since the early 1970s.

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First built were rapid transit "heavy rail" projects in San Francisco, Washington, Atlanta, Miami, Baltimore, and, currently, Los Angeles. As these systems were opening in the 1970s, light rail transit (LRT) took off, partially in reaction to perceived problems with established rail modes:

- Heavy rail cost too much and provided more capacity than medium-sized regions needed.
- Commuter trains had high labor costs; freight railroads had no incentive to run them.

Unlike heavy rail rapid transit, LRT offered short trains on lower-cost, mostly surface alignments. Unlike commuter rail, a train of light rail vehicles (LRVs) could be operated by just one person. New LRT systems are running in 12 North American cities previously without rail (8 in the United States, 2 in Canada, and 2 in Mexico). Two more are under construction, as are extensions elsewhere.

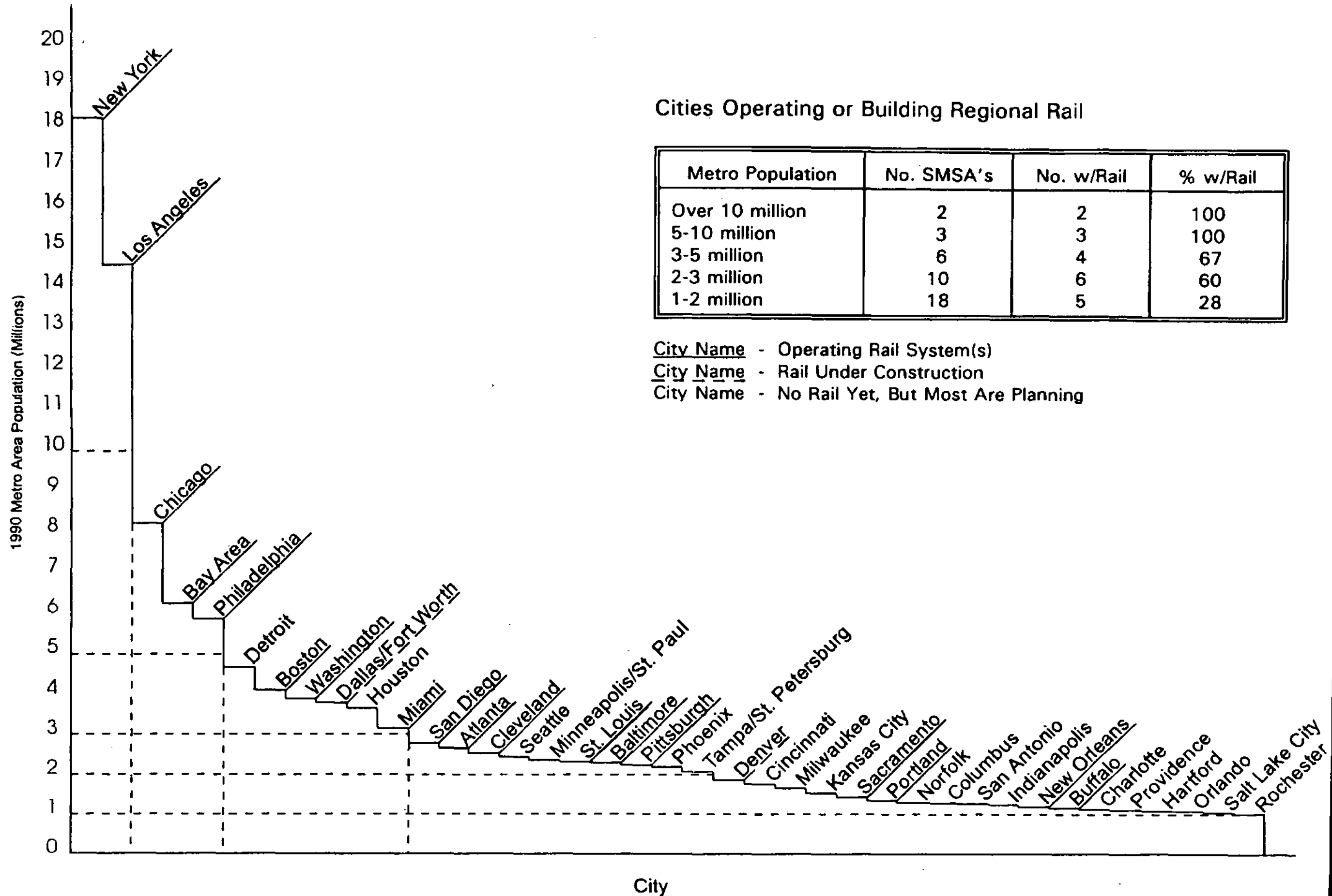
Perhaps even more surprising, the commuter train has been reborn. Agreements to reduce train crew sizes began to be negotiated about the same time that Congress passed the Staggers railroad deregulation act. These actions set the stage for less costly train operation and the growing realization that publicly subsidized commuter services could actually turn modest profits for the private railroads running them under contract to public transit authorities. Today, older systems continue to be renovated and expanded, and there have been three completely new commuter rail start-ups since 1989: in Miami; Washington, D.C./Virginia; and Los Angeles.

REGIONAL RAIL CONCEPT AND PRACTICE

What is regional rail and why is it important to transit in North America? Responding to these queries is this working definition:

> Regional rail: An emerging rail transit service concept and institution superimposed on a metropolitan region, employing conventional rail technologies, incorporating elements of older rail operations and infrastructure where they exist, and adding new links where required to integrate suburban, urban and downtown travel functions.

A shorter description would be to state what it does. "Regional rail distributes riders like rapid transit or LRT in the central business district (CBD), and provides express line-haul transportation like commuter rail between central cities and their suburbs." In the past decade, there has been a tendency to think of regional rail as using the "railroad" technology traditionally called com-



Metro Population	No. SMSA's	No. w/Rail	% w/Rail
Over 10 million	2	2	100
5-10 million	3	3	100
3-5 million	6	4	67
2-3 million	10	6	60
1-2 million	18	5	28

FIGURE 1 U.S conurbations of more than 1 million ranked by metropolitan population (*6*).

muter rail in the United States (*1*). This paper suggests that regional rail is more a service concept than a description of systems hardware and that, depending on various factors such as corridor lengths and trip densities, regional rail service may be provided by one or more of the rail modal technologies: heavy rail, commuter rail, and light rail.

Whichever technologies are used, regional rail must provide adequate capacity, a high order of rider comfort, and fast and reliable service, and it must be an environmental "good neighbor" in the community (*2*).

Some planners consider the ultimate regional rail systems to be in Europe, networks such as Paris' Réseau Express Régional (RER) or the S-Bahns in major German cities and Zurich, which blend local city rapid transit/light rail and national railway commuter/intercity rail. There is much to be learned from how the French, Germans, and others have re-formed their metropolitan rail systems. Nonetheless, regional rail is a complex and potentially daunting issue for North American authorities because its introduction requires strategies to

- Integrate the schedules and fares of separate operating entities,
- Connect lines using different technologies in a unified system, and
- Coordinate transit planning and regulation across multiple jurisdictions.

Creation of a regional rail network could be considered as the ultimate step in the evolution of a mature metropolitan public transport system. Discussions with a variety of transit professionals suggest that this process and the emerging concept of regional rail is occurring somewhat differently in two primary categories of North American conurbations:

- Coordination of extant lines that grew up around traditional commuter rail and rapid transit networks in older cities (e.g., Philadelphia), and
- Completely new rail systems in an increasing number of places where former rail services, if they even existed, had long since been discontinued (e.g., Los Angeles).

CHARACTERISTICS OF REGIONAL RAIL

Regardless of whether it is a reorganization and integration of traditional rail transit modes or a newly built system using one or more rail technologies, regional rail exhibits common characteristics:

- Integrates the traditional domains and roles of urban rapid transit and suburban rail. Integrates transit systems and subsystems selectively, for example, by providing common public information systems and signing as on the multimodal system in metropolitan Boston.

- Serves both urban and suburban parts of a metropolitan region, not being associated exclusively with either the core cities or suburbs. Regional rail connects both places.
- Spaces stations variably to account for varying densities of the areas served and whether stops serve dispersed origins or concentrated destinations.
- Routes directly through the CBD, to distribute within the CBD and provide suburb-to-suburb regional travel options.
- Uses high-performance trains, preferably electric, either multiple unit or locomotive-hauled push-pull sets. Regional rail may be diesel-powered, as in Chicago, although nonelectric propulsion limits rail's capability for direct CBD penetration.
- Operates high-capacity single- or bilevel rolling stock, with amenity levels appropriate to a high-density but seated ride.
- Conducts automated zoned fare system; the most advanced forms of regional rail feature self-service ticketing. Fares should be fully integrated with surface transit systems in the region, with no penalty imposed on intermodal transfers.
- Employs level boarding, using fully accessible high platforms or low-floor cars, to reduce station dwell times. However, Zurich, Chicago, and other cities provide examples of regional rail systems with low platforms.
- Serves multiple travel functions in an urban area including not only journeys to work in the CBD but also accommodating reverse commutes, express and local distribution trips, access to intercity transport (air, rail, bus), and recreation travel.
- Provides opportunities for institutional, regulatory, and other reforms.

Of the 18 U.S. metropolitan areas with operating rail systems, 12 have lines serving more than a single urban transportation corridor and thus may be identified as regional rail. Included are a range of systems in terms of size, technologies used, and regional population. These systems also meet many of the other characteristics outlined earlier and in Table 1. For comparative purposes, Table 1 also includes information for a "model" European regional rail system: Zurich.

TRADITIONAL RAIL TRANSIT CITIES

Regional rail could be expressed as the next step in an evolution of rail transit for older rapid transit and commuter rail properties such as New York, Chicago, and Philadelphia. This evolution, which has been in progress over the last several decades, consists of five phases, the last of which is implementation of regional rail:

- Phase 1: Preserve failing passenger rail (and bus) systems through public subsidies of private operators to prevent further route abandonment or discontinuation of services.
- Phase 2: Stabilize rail (and bus) transit systems with purchase or transfer from private to public ownership and the formation of public authorities with the obligation to continue essential public transit service.
- Phase 3: Rebuild railroad, rapid transit, or streetcar infrastructure and replace life-expired rolling stock to bring systems into a good state of repair and to project an up-to-date image to potential users. Rebuild transit properties that were allowed to deteriorate through deferred maintenance.
- Phase 4: Upgrade and extend rail transit service by applying new technology and operating innovations, by selectively restor-

TABLE 1 Key Characteristics of Regional Rail Service In Place on U.S. Systems

Regions and Modal Technologies (a)	Through Routing (b)	Intermodal Coordination (c)	High-Perf. Elec. Trains (d)	Integrated Fares	Level Boarding	Trip Functions Served by Regional Rail			
						CBD	MACs (e)	Leisure	Airport
Model System: Zurich (CR/LR)	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
New York/Newark (CR/HR/LR)	HR	Some	HR/LR/ Most CR	No	HR/ Most CR	Yes	Some	Yes	No
Chicago (CR/HR)	HR	Yes	HR	Some	HR	Yes	Some	Yes	Yes
Bay Area (CR/HR/LR)	Some HR/LR	Yes	HR/LR	Some	HR/ Some LR	Yes	Some	Yes	No
Philadelphia (CR/HR/LR)	HR/CR	Yes	Yes	Yes	HR/Some CR&LR	Yes	Some	Yes	Yes
Boston (CR/LR/HR)	Most HR	Yes	HR/LR	Yes	HR/ Some CR	Yes	Some	Yes	Edge
Washington (CR/HR)	HR	Yes	HR	Most	HR	Yes	Some	Yes	Yes
Miami (CR/HR)	HR	Yes	HR	Most	HR	Edge	Few	Some	No
San Diego (LR)	Yes	Yes	Yes	Yes	No	Yes	Few	Yes	No
Atlanta (HR)	Yes	Yes	Yes	Yes	HR	Yes	Some	Yes	Yes
Cleveland (HR/LR)	HR	Yes	Yes	Yes	HR	Edge	Some	Some	Yes
Baltimore (CR/HR/LR)	LR	Some	HR/LR	Yes?	HR	Yes	Some	Some	No
Sacramento (LR)	Yes	Yes	Yes	Yes	No	Yes	Few	Some	No

(a) Modal technologies: CR--Commuter Rail, HR--Heavy Rail, LR--Light Rail; (b) Suburb to suburb across the CBD; (c) Between rail modes and rail w/buses; (d) CR = push-pull diesel trains in NY/Newark (some); Chicago, Washington, Baltimore (most); Bay Area, Boston, Miami (all); (e) MAC-Major activity center.

ing former services, and by adding new extensions as regional growth patterns indicate a need.

- Phase 5: Rationalize and reorganize portions of existing rail systems into regional rail and add new links as necessary, thereby integrating and adapting networks and services to changing urban demographics and economics and coordinating transit with adjacent land uses.

Modifications exemplifying Phase 5 development may be observed in greater New York (subway rationalization, NJ Transit rail connections), Boston (reinstatement of Old Colony lines), Chicago (Wisconsin Central commuter rail), and the Bay Area (Caltrain extension to Gilroy).

NEW RAIL CITIES

As they grow ever larger, U.S. metropolitan areas must deal with the problems of moving masses of automobiles: congested highways and streets, deteriorated air quality, too much land used for parking lots, and bus systems that cannot attract choice riders because they are mired in the general traffic. An increasing number of these cities are turning to rail transit, almost always in the form of regional rail, to provide a viable alternative to automobile travel for commuters and other choice riders. Transit systems in these places also are going through a five-phase process:

- Phase 1: Preserve failing bus systems through public subsidies of private operators to prevent further route abandonment or discontinuation of services.
- Phase 2: Stabilize bus systems by purchase or transfer from private to public ownership and formation of public authorities with the obligation to continue essential public transit service.
- Phase 3: Rebuild and expand bus systems to bring them into a good state of repair. Rebuild transit properties that were allowed to deteriorate through deferred maintenance.
- Phase 4: Build rail "starter lines" in one or more key corridors to serve the region's principal arterial trunk routes with high-quality express routes, carefully integrating rail with a revised system of local and feeder buses, and with automobile park-and-ride lots.
- Phase 5: Expand and extend starter lines to create a fully developed regional rail system that continues to adapt over time to changing urban demographics and economics, and coordinating transit with adjacent land uses.

New systems that have reached Phase 5 include Bay Area Rapid Transit (BART), Washington and Atlanta, all heavy rail, plus Calgary (Canada) and San Diego using LRT. The other new U.S. heavy rail, LRT, and commuter rail cities all are working through Phase 4.

NEW-START APPLICATIONS OF REGIONAL RAIL ORGANIZING PRINCIPLES

Today's newer regional rail properties such as the Bay Area, St. Louis, Washington, and Atlanta lost their original rail service and infrastructure entirely back in the 1940s and 1950s. These cities started with a clean slate, fashioning new rail transit systems in part by adapting remaining fragments of the old abandoned systems. In the Bay Area, for example, the old Key System and Sacramento Northern rail properties begat BART. In Baltimore, the Northern Central and Baltimore & Annapolis alignments formed the base for the new Central Corridor LRT, and so on. Although real estate and infrastructure fragments of the former rail properties were inherited and recycled, obsolescent regulatory and institutional "baggage" was not.

In the smaller or less densely populated metropolitan areas such as Portland, San Diego, and Calgary, regional rail takes the form of light rail corridors linking both the urban and suburban parts of the metropolis. In more extensive or more dense metropolitan regions such as Atlanta, Miami, and Washington, regional rail takes the form of a hybrid heavy rail rapid transit/commuter rail that blankets the region.

EXAMPLES OF REGIONAL RAIL: PAST, PRESENT, AND FUTURE

Some aspects of the regional rail idea are hardly new. Serving today's sprawling U.S. urban regions, however, requires both adaptation of old practices (e.g., bus-rail timed transfers) and introduction of new innovations (e.g., single operator crewing of commuter trains using bidirectional equipment with automatic doors and combined with proof of payment fare collection methods).

North Shore Line: Regional Rail Precursor

Imagine a 140-km (85-mi) rail line using local streetcar tracks at one end of its line and operating jointly with heavy rapid transit trains at the other end. Imagine that this property ran its trains at speeds as high as 140 km/hr (85 mph) to compete with parallel commuter and intercity trains. Suppose service featured meals on board as well! It sounds like an absurd rail integration fantasy, and yet most will recognize this supposition as the now-defunct Chicago North Shore and Milwaukee Railway. This was an "interurban" that emulated local streetcars, intercity express trains, commuter rail, and rapid transit all in one ride between the Chicago and Milwaukee CBDs.

Cross-CBD Links in Mature Cities

Several attempts to develop regional rail in traditional rapid transit cities have met with varying degrees of success. The Queens Long Island Mass Transportation Demonstration Program of the 1960s spawned the idea of a super subway, applying the concept to the Port Washington Branch of the Long Island Rail Road. The originator of the term "super subway" (*3*) later regretted using it because it conveyed the impression that the city subway system would be extended into the suburbs. This notion created a backlash ("not in my backyard") among suburbanites who despised the city's subways (and perhaps those who rode on them).

In the early days of the Tri-State Regional Planning Commission, a series of travel demand networks were coded to test various proposals being refined for Tri-State's regional transportation plan. One of the most ambitious proposals tested was to convert the relatively lightly used Broadway BMT line for use by the Long Island Rail Road. Points of connection would have been at Brooklyn's Atlantic Avenue Terminal and the 63rd Street Tunnel under the East River. The often-proposed but only partially built Second Avenue Subway has also been suggested by planners as an upgraded version of rail rapid transit approaching regional rail standards.

The principal objective in these proposals was to avoid single stop or stub terminal operation for commuter rail within the CBD. New York/New Jersey, Boston, Chicago, and Philadelphia all inherited architecturally grand but functionally obsolete stub and stub-like terminals of former competing railroads. This configuration followed the model of the great European capitals with several stations, each positioned in the geographical sector where its builder railroad held exclusive domain.

The operational advantages of through-running suburb-to-suburb transit routes are well known and practiced extensively in bus transit and on several newer LRT systems such as Calgary and Sacramento. Through running increases the efficiency of subway lines entering Manhattan from Queens, the Bronx, and Brooklyn and dates from the era when the rapid transit systems were operated by separate, private managements. Rapid transit lines were through routed in Boston, Cleveland, Chicago, New York, Philadelphia, and other traditional rail transit cities, but their commuter rail lines were not, even when through station capability existed and was used as such by intercity trains (e.g., Penn Station, New York).

In the commuter rail sector, however, through running is discouraged by lack of critical links, conflicting physical standards, and institutional turfs. These conditions reduce trip, residential, and employment choices for urban and suburban residents. It is easier to commute 50 mi or more into Manhattan on NJ Transit, Metro North, or the Long Island Rail Road than it is to go 10 mi between densely settled places in Hudson County, New Jersey; and Queens, New York. Currently, these trips typically are being made by automobile through some of the highest-density transit service territory in the United States. All the conditions necessary to support transit are there: infrastructure, employment, and residential densities. Yet systems are linked neither physically nor operationally, so they do not serve new travel markets arising from changes in metropolitan demographics and development patterns.

New-Start Regional Rail Systems

In metropolitan areas that lost their rail transit and undertook to build all-new systems, the older rail transit CBD route patterns are not replicated. BART through routes and distributes along San Francisco's Market Street rather than terminating at Key System's East Bay Terminal. St. Louis' LRT through routes rather than stub ends, as its predecessor Illinois Terminal Railway did. Washington, Miami, Atlanta, Calgary, Sacramento, and other "new" rail properties through route rail services to provide suburb-to-suburb travel, as these properties' routes all begin and end in suburbs. Through routes also link opposite ends of both the CBD and the city. Finally, through routes tend to enhance services for a variety of travel functions, including airport access.

One might conclude from these observations that if the traditional rail cities were to build their systems all over again, they would serve the same corridors and locations. This time, however, the rail lines would be linked and operated differently to promote more interchange and broader travel choices.

Philadelphia Regional Rail: Center City Commuter Connection

Philadelphia was the first U.S. city to replace its commuter rail stub terminals with a cross-CBD tunnel purpose-built to enable through running. It helped that both formerly independent rail networks had already been supported by substantial subsidies from the city of Philadelphia and suburban counties before being transferred to public ownership and were controlled by a single public transit authority when the Center City Commuter Connection (CCCC) was finally implemented. The CCCC, a new line to Philadelphia International Airport, and the 12 inherited commuter rail branches together make up what may be considered the first of the older U.S. commuter rail systems to enter Phase 5, reorganization of older rail properties into a regional rail system.

Multimodal Regional Rail Systems

Regional rail in Philadelphia is more than the extensive commuter lines. The system also includes two fully grade separated rapid transit lines, Market-Frankford and Broad Street, and three suburban LRT lines, all interconnected with networks of city and suburban bus routes. Always bedeviled by inadequate funding (a plight shared by other public service providers in larger, older regions) and a troublesome city-suburban split at the policy level, the Southeastern Pennsylvania Transportation Authority has never been able to provide a truly attractive alternative for choice riders in terms of service frequency, reliability, and amenity. Thus, the full potential of the region's superb regional rail network remains unrealized.

Integrated regional transit systems in other countries provide an indication of what can be achieved. One of the best is Zurich. With a regional population about one-fourth of Philadelphia's (or about the same as Portland, Oregon; and Sacramento, California), Zurich residents enjoy a multimodal 14-line regional rail S-Bahn system incorporating commuter rail lines run by the national railway as well as local railways and three LRT lines. Railway S-Bahn lines use either EMU or electrically propelled push-pull trains. LRT S-Bahn lines use single- and twin-unit LRVs, with or without trailers.

Most lines are through routed, with the CBD in the middle of routes starting and terminating in outlying suburban towns. In addition, there is an extensive streetcar, trolleybus, and motor bus city transit system within Zurich itself, as well as local bus services in some outlying towns. Schedules are coordinated, and there is a unified fare structure. As a result, users experience it all as one system.

Through-routed S-Bahn lines penetrating the CBD operate through a new tunnel dedicated to their use. However, there are so many lines that tunnel capacity was immediately filled; so four S-Bahn lines continue to use the ground-level stub tracks in Zurich Hauptbahnhof (main railway station). Two of these lines are through routed. Drivers simply change ends during the 5-min station dwells. This is done reliably, hour after hour, day in and day out. To cover rare occasions when a train arrives downtown late, a spare train and crew are kept ready to pick up the second half of the run. The late equipment and crew then becoming the reserve train.

REGIONAL RAIL AND REGULATION

Recent federal initiatives and mandates—the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), Clean Air Act, Energy Act, and Americans with Disabilities Act—require transit practitioners to reconsider strategic planning options. Many of the physical requirements to comply with new mandates are embodied in regional rail: electric traction as a clean fuel, accessible level boarding using high platform stations or low-floor cars, and improved levels of amenities and enhancements to help lure automobile drivers. Where it exists today, regional rail demonstrates a high level of coordination and integration between transit modes, institutions, and governments. Regional rail, therefore, is consistent and supportive of fulfilling these requirements.

Under ISTEA, capital plans called transportation improvement programs (TIPs), long-range plans, and unified work programs of study must be coordinated through metropolitan planning organizations (MPOs). Although ISTEA leaves the structure of transit operations and institutional organizations as local metropolitan options, it does require formal coordination. It also requires states to develop statewide transportation plans. These state plans combined with the MPOs' regional plans provide a coordination mechanism among levels of government and between governments and transportation providers. ISTEA also establishes a climate for planning rail new starts, including regional rail.

PLANNING FOR REGIONAL RAIL

Recall that older metropolitan areas with rail are in the fifth evolutionary phase as described previously. Their rail operations are relatively stable, and properties are in a fair to good state of repair. Systems have expanded, in some cases by reopening dormant rail corridors. What is next?

New York provides some current examples of possible next steps. The Second Avenue Subway, when and if built, will most certainly not be just another line oriented only to local city service.

Very preliminary discussions are under way between three transit agencies—NJ Transit, New York Metropolitan Transportation Authority, and the Port Authority—on new trans-Hudson capacity linking midtown Manhattan and the rest of the region. The press has characterized this discussion most frequently as a proposed extension of the Flushing IRT to the Hackensack Meadowlands. However, this link could serve as the initial piece in a more extensive upgrading of rail transit services. As a $1 billion proposal, a new Hudson River crossing might also be the last such affordable project of its type. It must be adaptable to a variety of future technologies and modes. For example, by using dual-mode (AC/DC) commuter rail technology, the link could serve through-routed NJ Transit and Long Island Rail Road lines as part of a regional rail network while simultaneously relieving crowding at Penn Station. This kind of action, in turn, could facilitate some "capacity swapping" between Penn Station and Grand Central Terminal, using the latter's ample space for lines terminating in Manhattan and opening Penn Station for through-routing strategies involving Metro North Hudson or New Haven lines.

The issues arising from such a project are those same issues considered by new-start cities designing their regional rail. Which institutions will build and operate it? How will it be financed? On what physical standard will it be designed? How will it link to existing transit services? How does it rationalize operations and improve the existing transit network? Is goods movement a consideration? How will it serve changing patterns of demand? How should the facility be sized and designed to anticipate advances in technology?

These questions revolve about a central strategic dilemma: adapting inflexible rail infrastructures and entrenched institutions to meet changing travel demands, dispersing travel patterns, aging populations, and other demographic transitions and economic realities.

CONCLUDING COMMENTS

Total rail transit abandonments characteristic of the 1930s to 1950s now seem unlikely. Instead, new-start rail lines appear likely to appear in more cities, while older metropolitan areas will continue to rebuild and reorganize their existing rail systems and institutions.

Regional rail may be considered a new start in the broadest sense of the term, even in the older rail cities, because it requires a departure from conventional habits of planning, engineering, and administration. Regional rail is an opportunity to implement new operating practices and reforms, to investigate and apply technical innovations selectively, and to control costs while attracting new customers from markets that transit finds difficult to penetrate. It is an opportunity to integrate systems that remain separate for no good reason except historical happenstance.

Almost 30 years have passed since one astute observer recommended that the future of transit as a public service enterprise depended on the effective implementation of "integrated marketing packages, reflecting price, product planning, market research, and promotion designed to attract different classes of riders" and that transit undertakings needed to reorganize to "*sell* as well as *produce* transit services" (*4*). As one of today's regional rail managers observes, "the need for public transportation is unchallenged in the nation's large urban areas," but outside the top dozen or so metropolitan areas, "the need for transit is not so clear ... and transit must fight for every passenger" (*5*). In U.S. urban regions with a million people or more, and perhaps in some smaller cities as well, regional rail offers a concept that today's managers can use to coordinate and enhance the utility of multidestinational systems offering a range of integrated, high-quality transit services that can be sold across a spectrum of the traveling public.

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Regional Rail in a Low-Density Context

THOMAS G. MATOFF

Metropolitan Sacramento demonstrates many of the typical characteristics of the U.S. Sunbelt city. Population densities are low, the growing population and employment base is spread over a large area, and the traditional downtown core is relatively weak. Most growth has occurred since World War II. Automobile dependency is high; transit ridership is low—especially outside the old urban core. Commonly accepted indicators of the probable viability of rail transit service all point to a negative conclusion. Yet Sacramento is served by a regional light rail "starter" system that is generally considered to be a success: its ridership exceeds the system's preconstruction final environmental impact statement forecast, its operating costs are low, and its level of public acceptance is high. The system's success can be understood by focusing on the supply and demand aspects of the regional rail concept in the Sunbelt context. A demand for the kind of mobility provided by regional rail does exist in Sunbelt cities. An appropriately scaled regional rail product can be supplied to Sunbelt cities to meet this demand through the use of low-cost light rail technology. The use of low-cost construction and low-cost operation techniques in Sacramento to develop a regional rail product appropriate to the transit market in a low-density city is discussed.

Twenty years ago, rail-based public transportation systems did not appear to have much of a future in the American and Canadian West. West of Chicago, only the San Francisco Bay Area seemed to offer fertile ground for rail transit. There, the San Francisco Municipal Railway's remaining five-line streetcar system was being upgraded, and the Bay Area Rapid Transit (BART) System had begun operations. The Southern Pacific's Peninsula commuter train service was hanging on by a slim thread, under constant threat from a hostile operator on the one hand and an "all-BART" planning vision on the other.

There was no other rail transit service between the Mississippi and the Pacific Coast or, in Canada, west of Toronto. Efforts to establish new BART-inspired systems in Seattle and Los Angeles had faltered. More ominously, the trend of the nation's growth patterns seemed to suggest that conditions conducive to rail transit would never be duplicated outside of the old industrial cities of the Northeast and upper Midwest. Western growth, which was to say American growth, appeared to be concentrated in low-density boomtowns in the West and Southwest, where the automobile-based transportation system enjoyed unchallenged and apparently unchallengeable hegemony.

Some of the nation's most prestigious urban planning schools taught that the automobile-based development paradigm was an unmitigated good; the unparalleled mobility brought about by pervasive automobile ownership, cheap gasoline, and vast freeway projects was said to be the expression in movement of the spirit of American democracy. Proponents of transit and of the land-use patterns that might support the development of transit and especially rail transit systems in newer cities were often dismissed as antidemocratic elitists (T. Matoff, personal communication, Department of City and Regional Planning, University of California, Berkeley). Relatively few voices among urban thinkers were raised on behalf of public transportation, these largely from outside the mainstream of the planning profession (Lewis Mumford and Jane Jacobs come to mind; no doubt there were others).

Twenty years later, things seem very different. Rail transit systems have been built and are thriving in nine cities in western North America. More are being planned and are probably on the way. Two, Dallas and Denver, are under construction. In addition, rail transit has returned to several older eastern and midwestern cities where it had once been taken as gone for good. The automobile, and the culture it engendered, no longer appears to be taken so readily as the apotheosis of American democracy. Instead, one school of contemporary urban criticism sees the automobile as an agent of social disintegration, the instrument or pathogen that permits the restructuring of the metropolis to "eliminate social mixing." Los Angeles, the American motorist's New Jerusalem, is now seen by some as "Fortress L.A.,"

> where the defense of luxury lifestyles is translated into a proliferation of new repressions in space and movement, undergirded by the ubiquitous "armed response", ... Contemporary urban theory, whether debating the role of electronic technologies in precipitating "postmodern space," or discussing the dispersion of urban functions across poly-centered metropolitan "galaxies," has been strangely silent about the militarization of city life so grimly visible at the street level. Hollywood's pop apocalypses and pulp science fiction have been more realistic, and politically perceptive . . .. Images of carceral inner cities ("Escape from New York," "Running Man"), high-tech police death squads ("Blade Runner"), sentient buildings ("Die Hard"), urban bantustans ("They Live!"), Vietnam-like street wars ("Colors"), and so on, only extrapolate from actually existing trends. (*1*,p.223)

Among other reversals in urban planning dogma has been the successful application of light rail technology to meet regional transit needs in cities where transit is not "supposed" to do much of anything at all. The emergence of the San Diego Trolley in a city of previous transit obscurity is well-known. Less celebrated, but equally worthy of attention for the lessons it can offer, is the remarkable establishment of protoregional light rail service in California's capital, Sacramento.

SACRAMENTO: A SUNBELT ARCHETYPE

Metropolitan Sacramento demonstrates many characteristics typical of the American Sunbelt city. Before the Second World War, the old "streetcar city," which held almost all the urban development of the area, had a population of about 100,000, with a downtown to match: "a calm city of trees, green lawns and government buildings . . . [with] . . . something of the appearance of a southern river town" (*2*).

The city lies in the heart of California's Central Valley (Figure 1). Today, a population of 1 million stretches over 450 mi^2. Al-

821 Second Avenue, M.S. 151, Seattle, Wash. 98104.

FIGURE 1 State of California.

most two-thirds of the population lives outside the boundaries of incorporated Sacramento or any other city. According to the Planning Department of the Sacramento Regional Transit District, annual vehicle miles traveled are 31.5 million.

Sacramento is located at the intersection of two Interstate freeways, I-5 and I-80 and two federal highways, US-50 and US-99, also freeways. These facilities are characterized by growing congestion, a fearful prospect to those who have fled the Los Angeles Basin or the Bay Area only to see the profligacy of American transportation policy about to engulf them once again. There is also a growing understanding that additional freeway capacity can no longer be delivered in the area on a per-capita scale equivalent to that of the "good old" 1950s and 1960s. This is true for two reasons. The first is state and local financial constraints. The second is that Sacramento is an air quality nonattainment area, which faces the threat of federal intervention in air quality planning. Transit is now emerging, albeit slowly, in the region's consciousness as an air quality–friendly means of increasing capacity in major corridors.

Sacramento did have a local streetcar system that disappeared in 1947, but it served only the higher-density, more truly urban inner city that existed before World War II. The celebrated interurban services of the Sacramento Northern Railway connecting Sacramento north to Chico and southwest to San Francisco, and of the Central California Traction Company, connecting Sacramento with the valley cities to the south, disappeared before World War II. The vestigial local transit service has been publicly owned since the mid-1950s, first by the city of Sacramento and more recently by a regional transit district (an independent single-purpose government entity) formed in 1972.

The absence of local financial support for the system, coupled with continuing urban development at low density levels, prevented transit from achieving a significant role in the community. Thus, even though there are large numbers of state office workers, which one would think might readily lead to a fairly high transit market share, the peak-hour share of trips on public transportation to central Sacramento is about 15 percent and the overall market share in the metropolitan area for a typical weekday is only $1^1/_2$ percent.

With relatively few changes, the general description of Sacramento could be that of many Sunbelt "growth" cities of the American West. Thus the remarkable and unexpected arrival of light rail technology in this metropolis is particularly important because it suggests the possibility of a wider applicability of this technology in the growth cities of the Sunbelt. If transit can work in these cities, then it can work throughout the nation. Thus, light rail technology, as an appropriate technology for regional transit trips, can be an important tool in making transit a workable alternative in the United States. The reversal of urban transportation dogma would be complete.

DEVELOPMENT OF SACRAMENTO PROJECT

As the light rail concept is central to this paper, it may be useful first to establish a definition of light rail transit (LRT). The Light Rail Transit Committee of TRB defines it this way:

> Light rail transit is a mode of urban transportation that uses predominantly reserved, but not necessarily grade-separated, rights of way. Electrically propelled rail vehicles operate singly or in trains. Light rail transit provides a wide range of passenger capacities and performance characteristics at moderate costs.
>
> Light rail transit possesses many operating possibilities. A light rail vehicle can be operating in the middle of a busy street in one moment and function as a high-speed rapid transit train moments later. (*3*)

The essence of this definition is the distinction in the first sentence between "predominantly reserved" and "grade-separated" rights of way. The terms "light" and "heavy" as applied to rail do not refer to physical weight; they generally refer to the intensity of the civil infrastructure of the system. It is the predominance of grade-separated and exclusive rights of way that makes heavy rail systems "heavy." One might say that these systems are "heavily" engineered and that their construction carries a "heavy" price. Light rail, on the other hand, uses selective investment and resorts to grade separation only where necessary. That is particularly true in Sacramento and is the key to the low-cost nature of the rail installation in that city.

On the whole, American public transportation systems have not been managed since the 1950s in quite the same environment as a fully commercial enterprise. Heavy reliance on federal grants and, in states such as California, the availability of state funding, has tended to reduce the stricter discipline in the evaluation of capital investment that would be made by a private entity doing business on a purely commercial basis; this is not to deny that this permits (but does not require) other important public values to be considered. Managers, whether drawn from outside or from within the transit industry, do not always engage in the careful balancing of investment and benefit that is the essence of the light rail concept.

The tendency toward intensification of investment in designing rail projects appears both natural and strong. Operations staff usually have in mind the minimization of staff effort and the maximization of chances for a completely successful operation. It is easily understood why they would want to spend "free" money to provide a good operation and avoid both problems and blame. Engineering staffs do not wish to be faulted for underengineering a rail installation. The comparative lack of commercial discipline to link strategic managerial design decisions with investment can leave rail systems open to the evils of overdesign and overinvestment.

This danger had to be avoided, and was successfully avoided, in Sacramento. A low-cost ethic pervaded the entire project from the beginning because of the basic fact that either the system was going to be cheap to build and cheap to operate or it was not going to be built at all. Consequently, the design of the system was not based on a progression from abstract principles of excellence to a perfect rail solution—that is, on the direct application of design criteria of high standard to the development of the project, regardless of cost. Instead, the Sacramento system relied on taking advantage of real-world opportunities to do as much as could be achieved within limited funding capabilities.

The Sacramento light rail project was also not the result of a deliberately structured program of public investment made by governmental agencies. It was, basically, the result of a grass roots citizens' effort that took place at a conjunction of two historic events. One of these was the availability of federal funding for public transportation infrastructure through a program known as the Interstate Transfer Program. The other was the rapid development of North American interest in rail transit, particularly the rapid growth in the redevelopment or rebirth of the light rail idea in the mid-1970s and its strong reception by the administration of California Governor Jerry Brown.

The citizen involvement was initially spurred by the extraordinary opposition that developed in Sacramento to the idea of more freeway construction. Strong citizen hostility to a number of freeways planned for Northeast Sacramento led to a decision by the Sacramento County Board of Supervisors in 1974 to delete those projects from the county's transportation plan and, further, to prevent their rebirth by selling the rights of way that had been reserved for them. Citizens who had come together in the freeway opposition movement coalesced around the idea of recommending alternatives in still other freeway corridors, in particular, the important federal freeway corridor that had been purchased and reserved for a new high-speed bypass for I-80. The Modern Transit Society, which became a potent citizens group, began to advocate the use of that right of way for transit rather than freeway purposes. A coalition of this group with other environmental groups encouraged Sacramento County to establish a study group to evaluate potential transit solutions as alternatives in this corridor.

The Modern Transit Society had originally focused on the possible introduction of a historic trolley loop in the central city of Sacramento, but when evaluating potential reuse of the freeway corridor, it began to advocate light rail instead. This was an important change because it marked a shift in strategy from advocacy of a utopian transit policy to the advocacy of a practical regional transit service concept. That shift was a reflection at the Sacramento level of a broader rebirth of interest in the light rail idea, manifested in the first North American light rail conference sponsored by TRB and held in Philadelphia in 1975. The concept of the light rail idea was transmitted from this conference to Sacramento and, through the advocacy groups, gradually spread. With the support of the state government, which under Governor Brown's administration was looking for alternatives to highway construction, the Interstate highway was at local option deleted from the map under the Interstate Transfer Program and the capital funding authorization was transferred from the federal highway program to the federal transit program. The I-80 highway restudy occurred in 1977, 1978, and 1979, and the freeway was withdrawn in 1979.

Simultaneously, proposals to accommodate additional growth in travel demand were also under study in the Folsom Corridor leading directly east out of central Sacramento. The coalition of public and political support around the light rail idea in the first corridor led to its adoption in the second, as well. By the early 1980s, a formal alternatives analysis, a federal process that is required before federal funding of any rail project can occur had been completed on a project to build an 18-mi light rail line consisting of 9-mi routes in each of the two corridors, I-80 and Folsom, connected by streets running through the central city. Additional analyses and political consensus formation, which is required by the cumbersome federal procedures in the United States, occurred between the completion of the alternatives analysis in 1981 and 1983. Eventually—despite the determined opposition of the federal government during the Reagan Administration and crucially aided by the spirited lobbying of Sacramento-area congressmen—federal approval was secured. Procurement and construction occurred during 1983–1987. The system opened in two phases in 1987: the northeast I-80 line opened in the spring and the east or Folsom line, in the fall.

IMPLEMENTING LOW-COST APPROACH

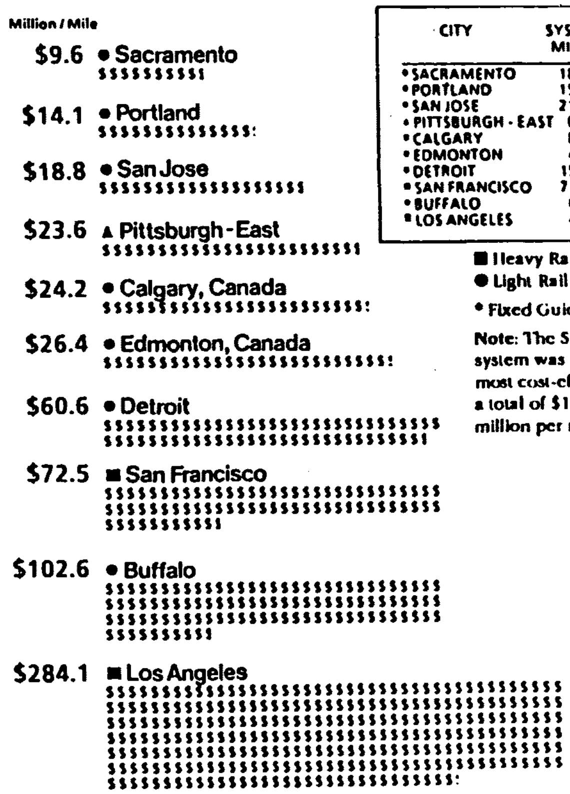
The cost of the 18-mi system as completed was $176 million including track, right of way, rolling stock, electrification, signalization, and urban amenities. This gives the Sacramento Light Rail System the lowest cost per mile of any federally funded system in the United States (Figure 2). Only the initial San Diego line, which was built without federal funding in the early 1980s, enjoyed a lower cost than Sacramento's $9.6 million/mi. How was this achieved, particularly when other light rail systems in the United States have required much higher costs per mile? (The Los Angeles–Long Beach Blue Line, for example, approximately 20 mi long, cost more than $700 million, or more than $35 million/mi.) The answer is obvious to anyone who looks at the system, but it has probably been best described by the line's original project manager, John Schumann, in his paper for TRB's 1988 Light Rail Conference (*4*). The key elements cited by Schumann are

- Use of available rights of way,
- Minimum investment for initial operation (the starter line concept),
- Proven off-the-shelf equipment,
- System design for low-cost operation, and
- Efficient service concept.

Available Rights of Way

The Sacramento system made extensive use of available rights of way. These are not in every respect ideally located for the project's market, but a perfect location would have required extensive right of way acquisition and, therefore, costs so high as to kill the project. Instead, as noted, the Sacramento concept was to use available opportunities rather than to proceed from a theoretical notion of the perfect development of a project. The existing rights of way that were available were in reasonable and usable locations and generally could be made to connect properly with most of the existing transit system (Figure 3).

In the northeast corridor, the I-80 bypass freeway right of way was available. This alignment parallels the Overland Mainline of the Southern Pacific Railroad and had several grade-separated highway overpasses in place. In addition, some parts of the bypass freeway had already been constructed. Because they led nowhere, these structures and rights of way could themselves be used and, indeed, made it possible for the northeast rail line to terminate in the center of the main I-80 freeway where the bypass lanes were to have diverged. Consequently, some of the northeast line is actually built on constructed but never used freeway structure, and



CITY	SYSTEM MILES	TOTAL COST (MILLIONS)
•SACRAMENTO	18.3	176.0
•PORTLAND	15.0	212.0
•SAN JOSE	21.0	394.0
•PITTSBURGH - EAST	6.8	160.8
•CALGARY	8.2	198.3
•EDMONTON	4.5	119.0
•DETROIT	15.0	909.0
•SAN FRANCISCO	71.0	5,150.0
•BUFFALO	6.4	656.6
•LOS ANGELES	4.4	1,250.0

■ Heavy Rail ▲ Bus Way
● Light Rail $ Million Dollars
• Fixed Guideway System

Note: The San Diego light rail system was locally funded and was most cost-effective - $15.9 miles at a total of $138 million or $8.7 million per mile.

FIGURE 2 Comparison of costs per mile in federally funded public transportation.

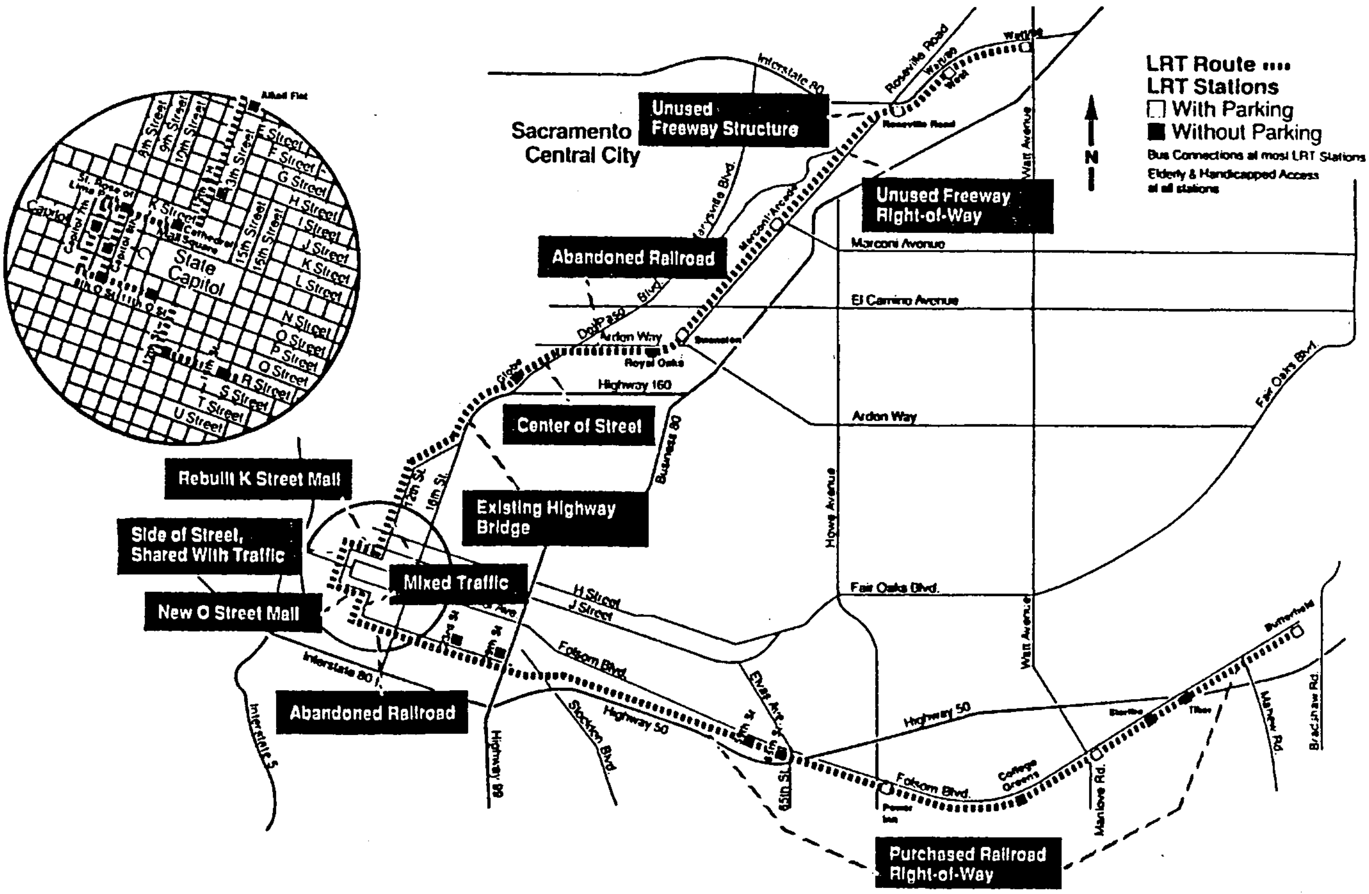


FIGURE 3 Types of right of way.

its terminus, including park-and-ride lots of 2,000 spaces, is located in the center of a very wide freeway. The terminus is well positioned to intercept motorists coming into the central area from the northeast. Four and a half miles of the northeast mainline were made available by the withdrawal of the freeway, the same action that made the funding available for the project. An abandoned railroad branch line and underused bridge and highway space were also available in this corridor.

To the east, available freight railroad branch line rights of way made possible the inexpensive construction of the Folsom line. Most of this line is built on part of the right of way of a light-density freight branch of the Southern Pacific Railroad. A single track remains in use for the railroad in the middle of a wide right of way that was acquired in the 19th century for multiple track operation that never occurred. It was thus possible to obtain a right of way suitable for light rail operation, which was actually well-located relative to the principal travel corridor to the east.

In the central city, it was necessary to interconnect these two radial routes, and a strategy using a variety of private rights of way and city streets was chosen. The resulting alignment through central Sacramento conclusively demonstrates the flexibility of the light rail concept. Entering the central city from the northeast, the line uses city street medians, side-of-the-road private rights of way (both single and double track), mixed operation with traffic in the manner of traditional streetcar operation, and an abandoned rail spur which ran in an alley between two major streets.

Two new pedestrian transit malls were also created. In the 1960s Sacramento, following a then-fashionable trend in city planning, had taken its main commercial street (K Street) and turned it into a pedestrian mall, complete with very large concrete sculptures and fountains, which came to be known as "tank traps." The mall was not successful, and businesses in the central area continued to decline. For its principal route into downtown, the light rail project removed the old K Street Mall and reconstructed five blocks of it (between 7th and 12th Streets) into a combined light rail and pedestrian mall. The concept was based on the Zurich Bahnhofstrasse, which has been cited elsewhere as the quintessential transit pedestrian mall. Along O Street, a second, new rail/pedestrian mall was created on a street that had served principally as a parking street for state office buildings; the advent of light rail resulted in the development of a pleasant, new urban environment on a street that had been reduced to the status of a parking lot.

Minimum Investment in Infrastructure

In almost every aspect, a minimalist approach was used on the starter line. The concept was to build a two-corridor line that made sense in and of itself but that did not provide much more in the way of infrastructure than was necessary to put the line into initial operation. More elaborate amenities and more significant infrastructure were left to the future in the event that the community should find them necessary.

The line as built was 60 percent single track (Figure 4). Demand analysis and operations simulations demonstrated that a 15-min headway on the 18-mi line would be sufficient to meet initial peak demand and could be sustained with only eight trains. The meeting points of these trains were calculated and double-tracked sections placed at those locations. The downtown segment was double-tracked from the beginning. The single-track, eight-train concept also dictated a small car order. The original starter line required only 26 cars when it was opened.

Whenever possible, existing structures were used. Of 16 major structures on the line, 10 were already in existence. Three new grade separations were constructed and a short new bridge was built over Arcade Creek. The most important additions were two major new viaducts, built to carry the light rail line itself over mainline railroads. These were built as single-track structures to keep costs down.

Standard railroad track, meeting standard American Railway Engineering Association criteria, was used. In this way, the procurement of expensive special work or street rail was avoided. The project employed used tie plates discarded from another railroad. The line is only partly signalized, and there is no automatic train stop. Where it is signalized, standard American railroad practice was used, except for a block indicator system not using vital circuitry that was put in place to govern entrance into single-track segments where low-speed operation is the rule.

Stations are simple (Figure 5). Taking advantage of Sacramento's mild climate, the stations consist of simple platforms and structures that are not significantly more elaborate than bus shelters. The treatment of the two pedestrian malls was also relatively inexpensive. No granite or marble was used. The malls are paved with pleasant and attractive but inexpensive, mass-produced, interlocking concrete pavers. Local opportunities for stations were used where they were available. At Eighth Street and Capitol Avenue, the California Employment Development Division building, which crosses over the street, was used a shelter for a station. At 29th Street, the I-80 freeway structure itself forms a shelter for the station.

The operations and maintenance facility is extremely modest. The building provides maintenance facilities, work areas for maintenance of way, parts storage, and the basic facilities and offices. There are no frills. The site of the facility and yard is within the abandoned interstate freeway right of way and the initial storage yard was laid out for the 26-car fleet. No superfluous trackage was provided, although space was reserved for more track to accommodate a larger fleet in the future. To keep the facility down to its $4 million budget, there were some sacrifices, including a body repair bay and paint booth that are only now being added. A new maintenance-of-way building and paint booth is also being added. Double track is now 50 percent for future capacity.

Off-the-Shelf Equipment

The project emphasized the use of proven off-the-shelf equipment. There is nothing dramatically new in the technical aspects of the system. The light rail vehicles are Siemens Duewag U-2-type cars, with some modifications (Figure 6). The project could not afford to experiment with new and exotic forms of rolling stock. Today with a total fleet of 36 cars, 32 are regularly scheduled in each peak. Failure, for mechanical reasons, to make pull-out is almost unknown, and the cars regularly operate 100,000 mi between mechanical failures.

In the area of traction electrification, the substations are domestically available, off-the-shelf units identical to those of San Diego's Trolley and manufactured by Control Power Corporation. The overhead contact wire system is standard Ohio Brass overhead of a kind that can be found in other North American cities; like the substations, it is of domestic manufacture.

Design for Low-Cost Operation

Economy in operation was itself an important design principle. The system was designed with long platforms for long peak trains. The platforms are 320 ft long so that four 80-ft cars can be used in rush-hour trains. The system is therefore designed for long trains rather than short headways. The standard, all-day 15-min headway on the system is maintained through the peak period, and additional capacity is handled by lengthening the trains instead of putting more trains into operation (Figure 7). In this way, fewer operators need to be hired and less double track is required. Single-car trains are operated at night and on weekends and two-car trains during the day on weekdays.

The proof-of-payment fare collection system is used on the system (Figure 8). A four-car train is thus staffed by only one train operator; there is no conductor and there are no attendants in the other cars or in the stations. The system is derived from the European fare collection practice, which was first used in the United States in San Diego and has been found to be successful in North America.

Control of the system is handled by simple two-way radio. There is no mimic board; there is no remote control of switches; indeed, there is not even remote control of substations. This system is inexpensive and, although more gadgets might make life more pleasant for the operating staff, the system is simple and inexpensive and appears to work about as well as its more sophisticated counterparts.

Efficient Service Concept

Finally, the entire concept of the line was as a trunk system that would replace the line haul segments of bus routes linking the central city with outlying areas (Figure 9). As a result, with the rail system in place, bus routes that formerly ran through to the downtown area now operate as connecting lines at major rail system stations. These stations are also de facto timed-transfer focal points for the bus service. The number of buses coming to downtown from the two corridors now served by the rail system has been reduced drastically in comparison with the number previously operated through to the central business district (CBD).

Some aspects of this service concept are worthy of special notice. It is sometimes asserted that this arrangement is undesirable because it forces a transfer between modes and thus depresses ridership in comparison with the through express line concept. Actually, the evidence appears to suggest the opposite. Some loss in patronage may occur in one relatively small market, but this loss is apparently more than compensated for by increases that result from the superior network connectivity produced by concentrating transit connections at principal stations.

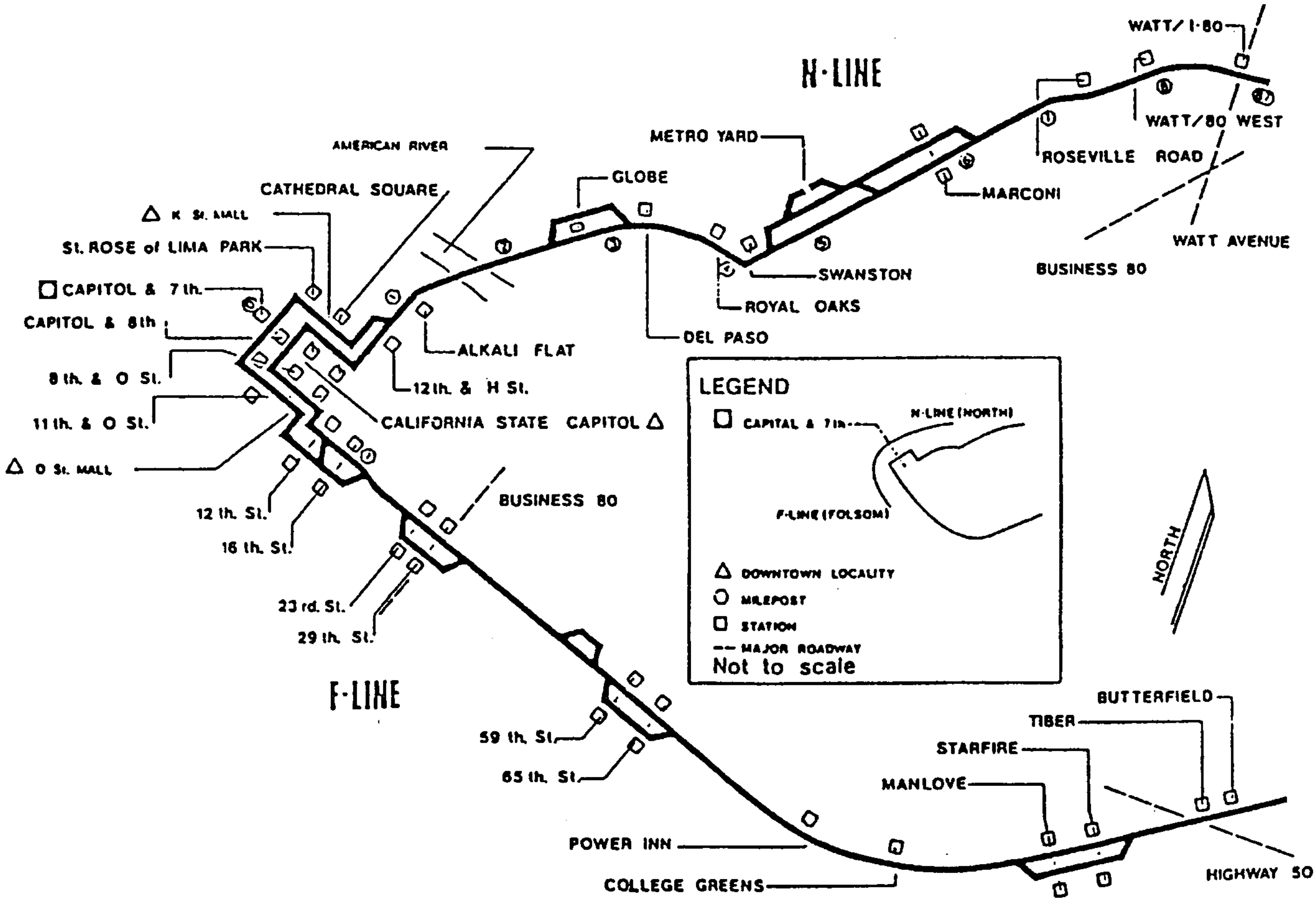
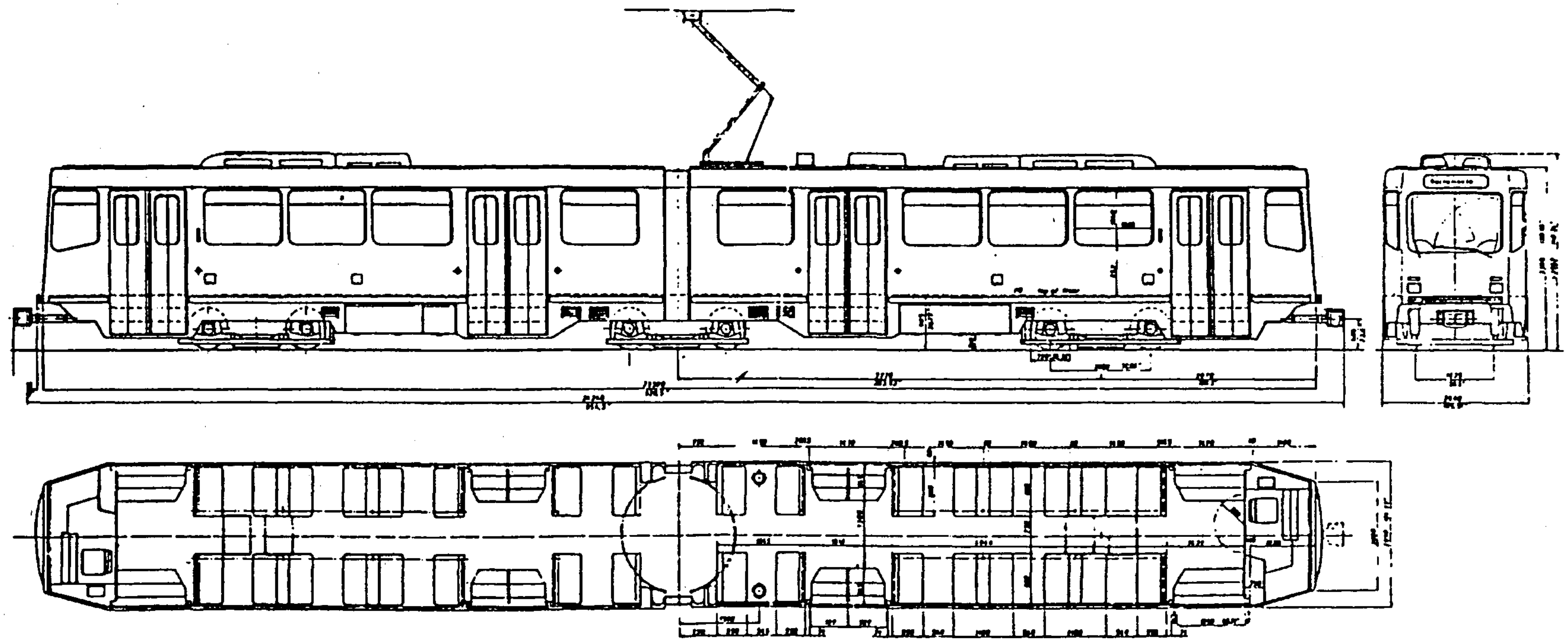


FIGURE 4 Rapid transit metro track schematic.

FIGURE 5 Typical station shelter, Alkali Flat Station.



MANUFACTURER: Siemens-Allis/Duewag
MODEL: U2A (air conditioned, tinted windows)
HEIGHT: with pantograph down 12.6FT
WIDTH: exterior 8.7FT

LENGTH: including couplers 79.6FT
WEIGHT: empty 77,800LBS
SPEED: maximum permitted 50MPH
CAPACITY: 64 seated, 175 standing

FIGURE 6 Sacramento light rail vehicle.

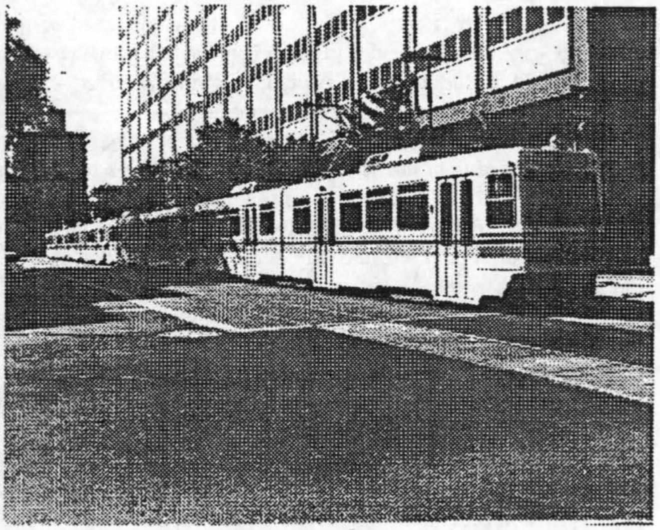


FIGURE 7 Four-car rush-hour train.

FIGURE 8 Ticket vending machine.

Express buses may serve one market well—typically, a "one neighborhood to the CBD in the peak hour" market—but they cannot provide the ubiquitous service that is more consistent with contemporary "everywhere-to-everywhere" transportation patterns, especially those of Sunbelt cities. Thus, it appears that the introduction of regional rail trunk routes and their associated bus networks may have the ironic effect of improving the quality of non-CBD transit trips. Obviously, this is a very important consideration given the dispersed nature of travel patterns in American cities. This may explain the otherwise counterintuitive phenomenon that per-capita ridership on North American transit systems seems to be positively correlated with the transfer ratio (*5*,p.381). In other words, on a systemwide basis, high patronage appears to be associated with heavy transfer traffic and with frequent local service rather than infrequent peak-hour CBD "one-seat ride" express buses. In this context, the introduction of transfer opportunities and the by-product of enhanced network connectivity can be seen to be a progressive service design strategy.

RESULTS

The improvement of connecting service reliability, bus-to-bus as well as bus-to-LRT, at LRT station/transit centers, has made the entire regional transit system more attractive. Total boardings increased from 13.8 million to 22.6 million, or more than 60 percent, between the last year of all-bus operations (1986–1987) and the most recent full year (1991–1992): about a 10 percent per year compounded rate of growth. Service on Sacramento's light

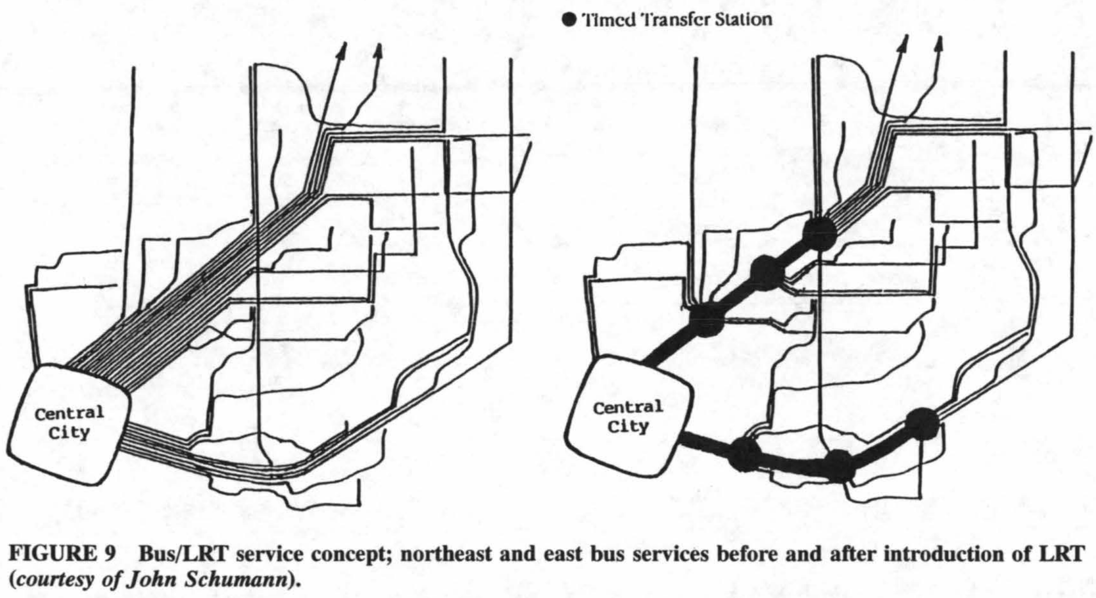


FIGURE 9 Bus/LRT service concept; northeast and east bus services before and after introduction of LRT (*courtesy of John Schumann*).

rail system was introduced in phases. The Northeast Line from Watt Avenue/I-80 Station to downtown was opened in March 1987; trains began running through to Butterfield Station on the Folsom Corridor line that September. The length of the service day was somewhat limited for the first year, and shorter service days at 30-min headways were operated on weekends. Rail/bus integration was only partly implemented.

Later, in 1988, weekend schedules were standardized and connections improved. Ridership figures in the first year fell short of the 20,500 projected in the final environmental impact statement, a fact that delighted some anti-rail groups and was quoted in reports that the Sacramento Regional Transit District still finds itself having to refute publicly.

With the final increments of service put into place in April 1989, the system reached full operational status. With the network concept in place that had been used to make the ridership projections in the first place, the line had achieved 18,000 boardings per weekday on school days and 16,000 per weekday during the summer of 1989. The projected ridership of 20,500 was achieved by 1990.

Weekday ridership on the light rail system peaked at an average of 24,500 in February 1992 but has declined somewhat in the wave of the recession and a July 1992 fare increase. In July 1993 average daily boards were 22,800, still roughly 10 percent above the final environmental impact statement projections—and this during the traditional summer patronage "trough."

The entire LRT operation is staffed by 114 people, which includes light rail administration, the Light Rail Transportation Department (train operators and supervisors), the vehicle maintenance staff, the maintenance-of-way function, and fare inspection. If the rail system were an independent operation, another 9 or 10 positions might be assigned to it, but in any event it is notable that the system carries more than one-fourth of the passenger load of the district and one-third of the passengers miles, with approximately one-sixth of the staff.

The operating budget of the system for fiscal year 1993–1994 is $7.6 million, representing approximately 13.3 percent of the budget of the district as a whole. Some of the overhead of the system is carried in other departments, but in terms of the work accomplished for the district, it is definitely more productive than the other segments of the district's operations (*6*).

Finally, in terms of public acceptance, there can be no doubt that the advent of light rail service has greatly enhanced the public acceptability of transit in Sacramento. As noted, metropolitan Sacramento has represented a superficially unfriendly environment for public transportation. Until recently, there was no local source of funding for public transportation. Parking is pervasive and usually free. Attempts to establish local tax support to maintain and enhance the transit system in the past were rebuffed by the voters. However, in November 1988 the voters of metropolitan Sacramento approved a small sales tax for the support of public transportation; this has made possible some enhancements to the system. The advent of regional light rail service in Sacramento is unquestionably a principal contribution to that public acceptance and expression of support and is the factor that has made public transportation a serious component of regional transportation planning and policy.

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Bay Area Rapid Transit District Regional Rail Planning

MARIANNE A. PAYNE

In 1956 the ultimate regional rail plan was proposed for the San Francisco Bay Area: a seamless, uniform mode encircling the bay. A 71.5-mi portion of the original core Bay Area Rapid Transit (BART) system was adopted by voters in 1962 and completed in 1974. It has taken many years within the complex Bay Area decision-making arena to implement the next generation of BART: 35 mi of new track scheduled to open within the next few years. Although further BART extensions remain unfunded, the vision of a regional rail system that "rings the Bay" has been brought within reach with an affordable plan to implement 200 mi of commuter rail service. The BART Extension Program and the practice of regional rail planning at BART are reviewed. It is concluded that the BART regional rail system can be multimodal and that service in a corridor can take many forms as it evolves over time.

In 1956 a comprehensive plan for regional rapid transit was completed for the Bay Area. As originally conceived, the Bay Area Rapid Transit (BART) system would have encircled the San Francisco Bay and reached north across the Golden Gate Bridge, joining nine counties into a regional metropolis. The plan identified a core system for initial development that would serve the population of the present and future; a second-stage system and routes would be constructed in subsequent stages (Figure 1). In essence, the ultimate regional rail system was envisioned: a seamless, uniform mode serving the entire Bay Area.

Today, almost 40 years later, the Bay Area population has doubled. The 71.5 mi of the original core system, adopted by voters in 1962, was completed in 1974 and has served more than a billion riders over the past two decades. Major strides have also been made toward implementing the BART Extension Program over the past two decades. This is due largely to extensive planning efforts that have significantly increased the cost-effectiveness and public support for the program. Thirty-five mi of new BART track and 11 new stations are scheduled for completion within the next few years. Although Phase 2 and 3 projects remain largely unfunded, efforts to advance project readiness continue and the vision of a regional rail system that "rings the bay" has been brought within reach with a plan to implement interim commuter rail service in the unserved corridors.

BART EXTENSION PROGRAM

Overview

The Bay Area political environment offers a challenging environment in which to implement a regional rail system. The Bay Area is a diverse nine-county region. There are 17 transit operators in the region, 4 of which operate rail transit. Overseeing it all is the Metropolitan Transportation Commission (MTC), which is responsible for setting regional funding priorities for transportation projects. Within this environment, a competitive, mode-specific advocacy has developed. At last count, there were approximately 49 proposals being sponsored by 19 sponsors.

BART is governed by a nine-member elected board of directors that represents geographic areas within the three-county BART District. After the "big bang" of new rail in 1972, a phased approach to implementing BART extensions was adopted by the BART Board (Figure 2). Service is planned for incremental implementation in major corridors both within and outside the BART District subject to cost-sharing agreements: Pittsburg-Antioch, Livermore-Pleasanton, Fremont–South Bay, San Francisco Airport, West Contra Costa, Oakland Airport Connector, San Francisco, San Ramon Valley, Santa Clara, and San Mateo counties (Figure 3). The ultimate long-range goal is to fulfill the vision of BART as a regional rail system that circles the bay and beyond. The challenge to attaining this goal: achieving a regional political consensus on funding.

Funding

In 1988 MTC adopted Resolution 1876, a comprehensive regional funding agreement for new rail starts and extensions in the nine-county San Francisco Bay Area. The product of lengthy negotiations among local officials and legislators at state and national levels, the agreement provided the momentum needed to secure significant amounts of local, state, and federal funds for adding nearly 40 mi to the region's rail network. The core of the plan (Figure 4) is the extension of BART in four directions nearly simultaneously: the three Phase 1 East Bay extensions (within the BART District), and the extension of BART to the vicinity of the San Francisco International Airport in San Mateo County. Other projects in the plan include partially funding three light rail transit projects in San Francisco, extending Caltrain in San Jose, moving the San Francisco terminal for the Caltrain commuter rail system closer to downtown, and extending light rail along the Tasman Corridor in Santa Clara County.

The plan is predicated on an innovative financing scheme:

- San Mateo County will buy into the BART system by paying \$200 million (1990 dollars) to help finance East Bay rail extensions.
- San Mateo County also will pay 25 percent of the cost of building a BART extension to the San Francisco International Airport.
- Bridge tolls will help pay for rail extensions that serve the bridge corridors.

Bay Area Rapid Transit District, 1000 Broadway, 6th Floor, Oakland, Calif. 94607.

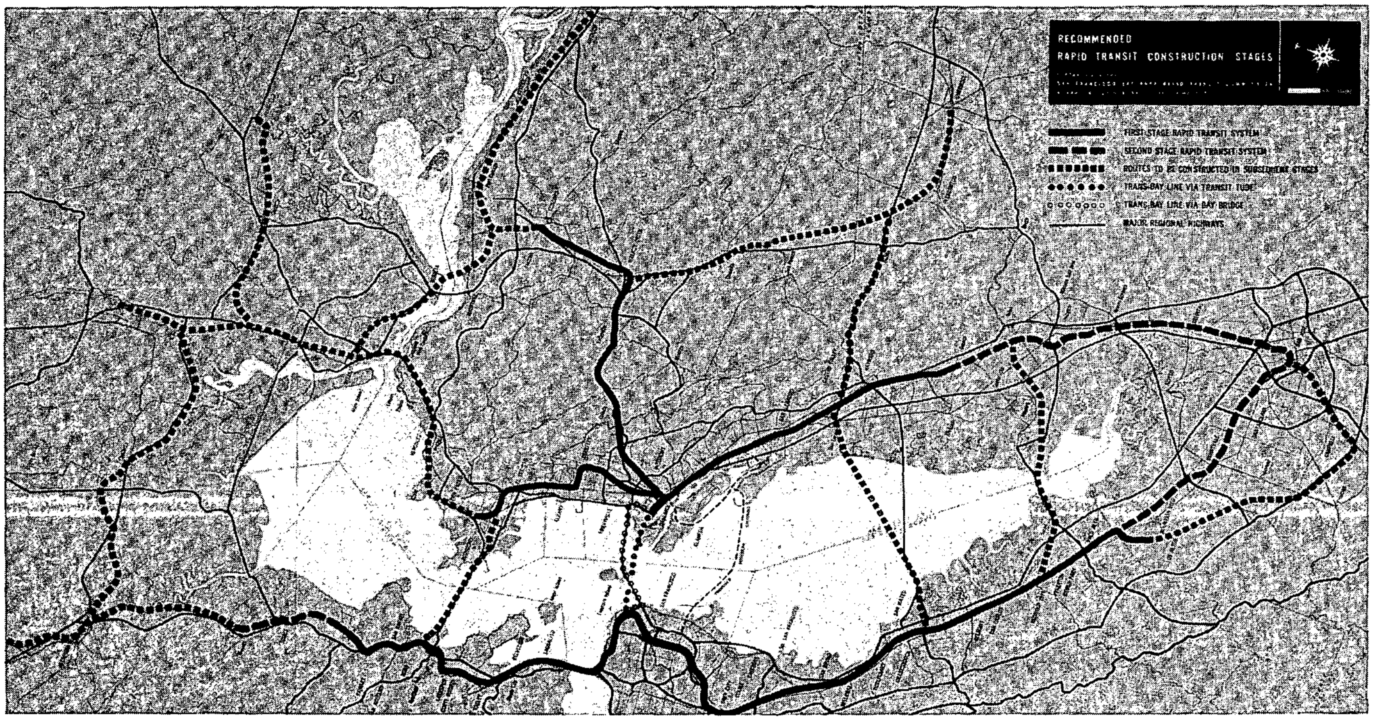

FIGURE 1 1956 Regional Rapid Transit map.

EXTENSION PROGRAM

Nearly 50 percent of the total funding for the extension will come from local sources, including new half-cent sales taxes approved in Alameda, Contra Costa, San Francisco, and San Mateo counties. State funds will finance 21 percent of the costs; federal funds, less than 30 percent.

Program Status

Planning has been completed, and construction crews are building three Phase 1 extensions of the BART system: Pittsburg-Antioch, Dublin-Pleasanton, and the Colma Station Extension. Planning and preliminary engineering work is under way on the San Francisco Airport Extension, and preliminary engineering has been completed for the Warm Springs Extension. Mandated by public vote and funded extensively with local funds, the Bay Area has high expectations for these projects and a unique sense of ownership. The public has demanded that these projects be completed on time and within budget.

BART has embarked on an ambitious Phase 1 extension program aimed at meeting and exceeding these expectations. Simultaneously, BART has sought to advance the Oakland Airport Connector Project. Although this project is identified as a Phase 2 project, policy requires that it be established before or at the same time as an extension of BART to the San Francisco Airport.

When complete, the Phase 1 extension program will add 34.5 mi of new double track, 11 stations, and more than 18,000 parking spaces in Contra Costa, Alameda, and San Mateo counties. The Oakland Airport Connector Project will provide a vital 3.24-mi link to the system. All of these projects are described in the following.

Pittsburg-Antioch Extension

In the East Bay, the Pittsburg-Antioch Extension will link western and burgeoning eastern Contra Costa County with nearly 8 mi of new BART track. One construction contract was completed last year, eight others continued or will start up this year, and the last will kick off in early 1994. Estimated to cost $506 million, this extension will serve an estimated total of 12,000 average daily riders at the new North Concord–Martinez Station in 1995 and the new West Pittsburg Station in 1997.

Dublin-Pleasanton Extension

In neighboring Alameda County, the $517 million Dublin-Pleasanton Extension experienced similar momentum, with one construction contract completed last year, eight more up and running, and three others set to start up this year. The longest of the Phase 1 extensions, this new 14-mi line will attract an estimated 22,480 average daily riders to new stations in Castro Valley and the cities of Dublin and Pleasanton by late 1995.

Colma Station Extension

On the peninsula, the Colma Station Extension—a first step to the San Francisco International Airport—continued to advance ahead of schedule with two construction contracts completed and all others in motion. Due to open in 1995, this 1.6-mi extension is projected to serve 18,000 average daily riders and cost an estimated $170 million.

PHASE	INSIDE CURRENT DISTRICT OR UNDER FUNDING AGREEMENTS
I.	North Concord-West Pittsburg[2] Irvington-Warm Springs[3] Castro Valley - Dublin[3,8] MUNI Metro Extension Project[4] Colma-Tanforan-San Francisco Airport[5]
II.	Pittsburg-West Antioch-East Antioch Pleasanton-West Livermore-East Livermore[3] San Francisco[6] San Pablo-Hilltop Oakland Airport Connector[7]
III.	San Francisco[6] Pinole-Hercules/Rodeo-Crockett San Ramon Corridor

NOTES:

1. The several segments shown under each Roman numeral are understood to be implemented concurrently, to the extent that funding is available. BART will be the operator for any new heavy or light rail transit starts or extensions within the three BART counties.

2. To be extended east beyond West Pittsburg as funding permits, per SB 1715 of 1988.

3. Third station may be constructed only with funds additional to those identified in MTC Resolution 1876 (as revised in 1989).

4. The San Francisco Project is identified through coordination with the City and County of San Francisco as the MUNI Metro Extension to the CALTRAIN Depot South of Market.

5. Agreement of February 28, 1990 with SamTrans to proceed with SFO extension, subject to BART project approval.

6. Specific San Francisco Project to be identified through coordination with the City and County of San Francisco. Section 29034.5 of the California Public Utilities Code lists an extension of District services and facilities to the northwest section of the City and County of San Francisco as a District service commitment.

7. A people-mover, or some other mode of travel, to the Oakland Airport to be established before or at the same time as an extension of BART to the San Francisco Airport.

8. Funding from Proposition 116 shall not be allocated to the Warm Springs Extension (WSX) until funding for the Dublin-Pleasanton Extension has been guaranteed.

PHASE	OUTSIDE CURRENT DISTRICT
I.	Milpitas
II.	Millbrae-Menlo Park Milpitas-San Jose
III.	Menlo Park-San Jose

9. Subject to a satisfactory cost-sharing arrangement with San Mateo and Santa Clara Counties and project approval by BART. Pursuant to Section 29034.5 of the California Public Utilities Code, only non-District funds may be spent by the District for the purpose of extending services and facilities outside of District's January 1, 1971 boundaries until the District meets specified service commitments within the 1971 boundaries.

FIGURE 2 BART extension staging policy.

San Francisco Airport Extension

Concurrently, environmental studies and preliminary engineering are proceeding on the San Francisco Airport Extension. Six major alternatives and three related design options are now undergoing intense scrutiny, and the debate over an external or internal station continues. A final decision and project adoption is scheduled for fall 1994. The locally preferred alternative, or proposed project, includes 6.4 mi of new BART track extending from Colma to new stations at Hickey, Tanforan, and the airport.

The airport extension is estimated to cost between $757 million and $960 million, depending on the final route alignment and whether a subway option is ultimately approved. It is forecast that 42,976 average daily riders will be attracted to this extension when it opens toward the end of the decade.

Warm Springs Extension

The Warm Springs Extension will extend BART 5.4 mi from the existing Fremont Station to new stations at Irvington and Warm Springs in southern Alameda County, thus advancing BART closer to Santa Clara County residents. Projected to cost $540 million, the Warm Springs Extension will provide combined parking for approximately 3,500 vehicles. Final design was halted in the summer of 1993, however, because of pending litigation and a funding shortfall.

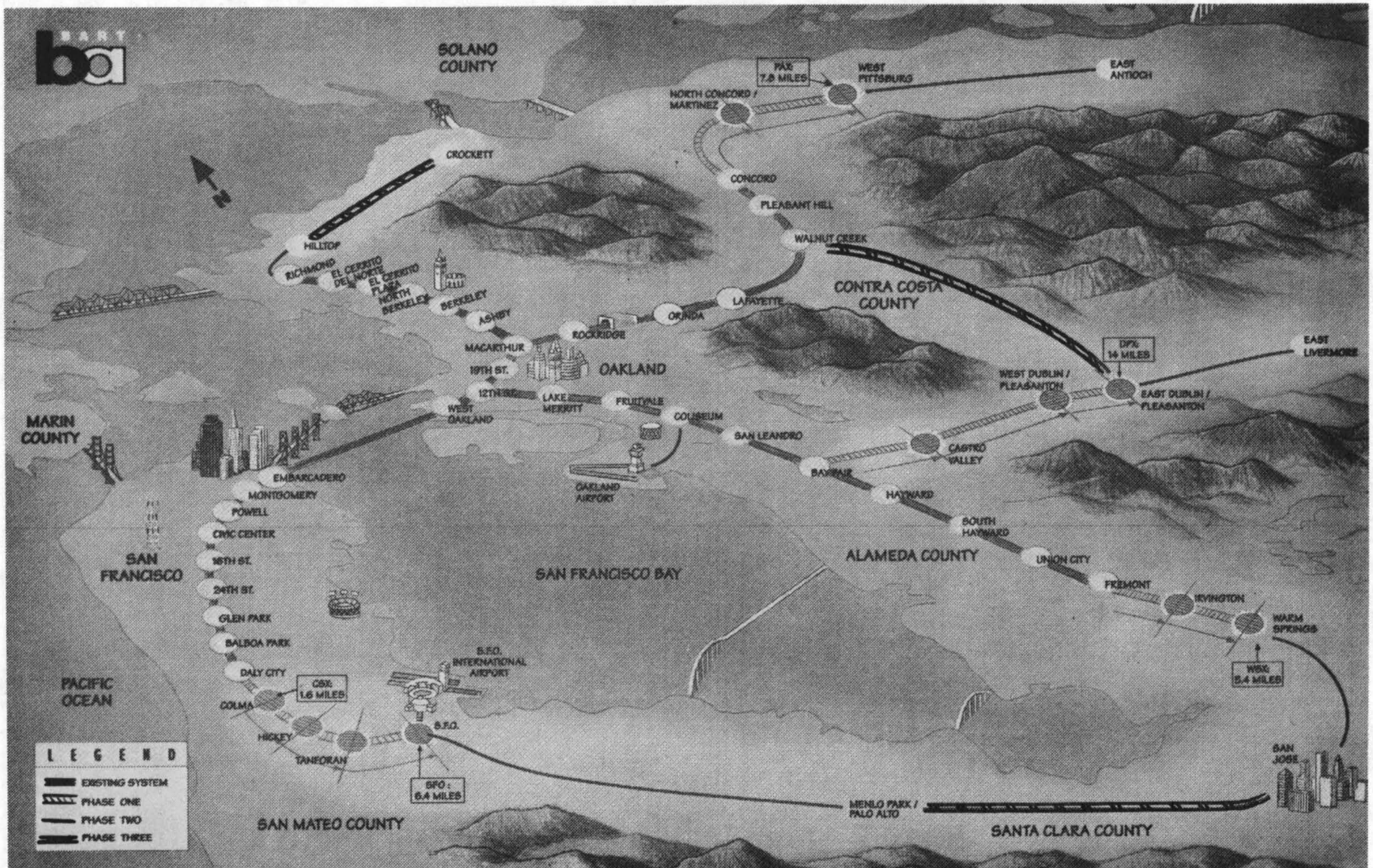

FIGURE 3 BART extension program map.

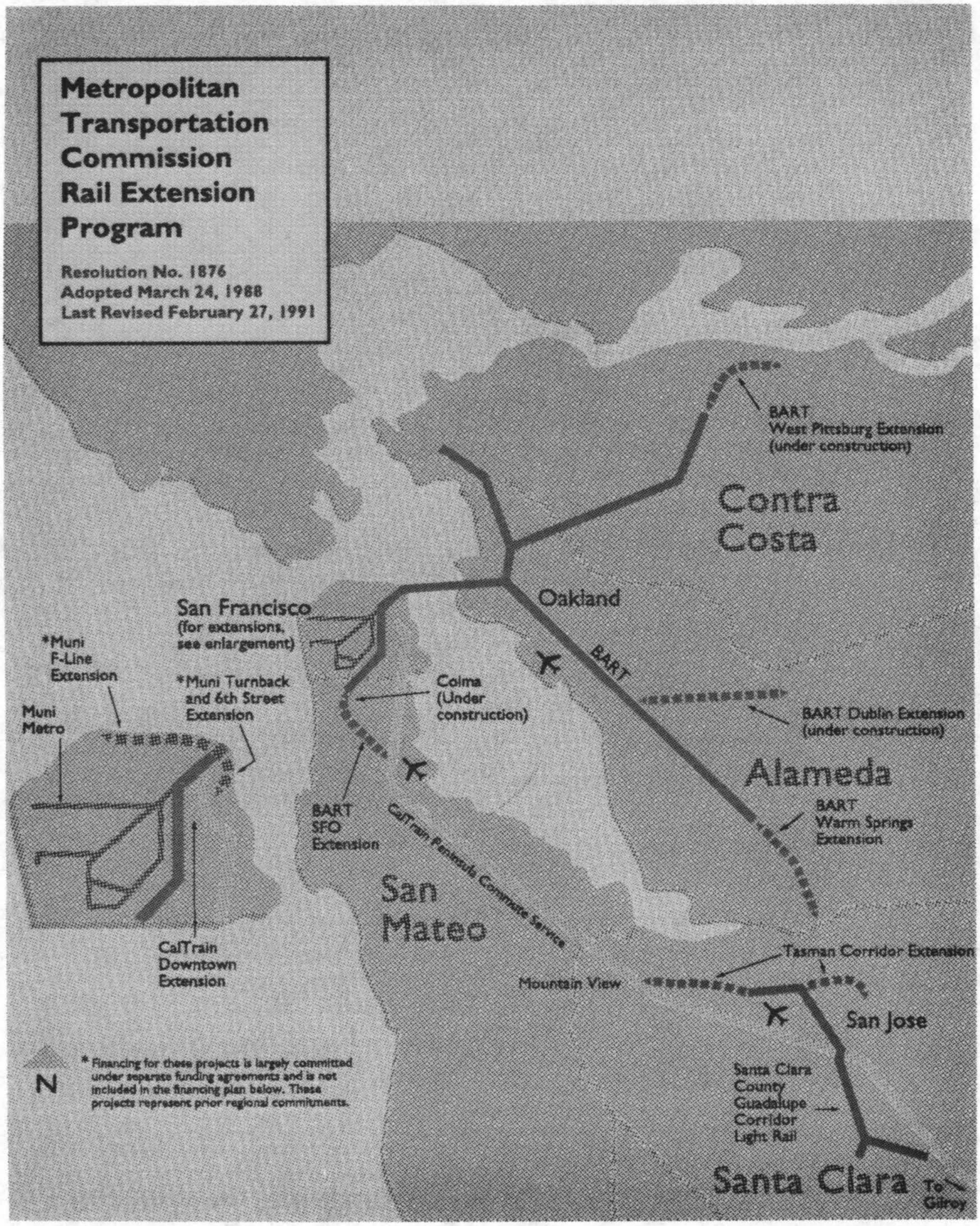

FIGURE 4 MTC rail.

Oakland Airport Intermodal Connector Project

The Oakland Airport Connector Project, under study since the 1970s, is envisioned as a fixed-guideway connection between the BART Coliseum/Oakland Airport Station and the Metropolitan Oakland International Airport, a distance of 3.24 mi. BART, in partnership with the Port of Oakland and AAI Corporation, was recently selected by FTA as one of three finalists for grants to support the Suspended Light Rail System Technology (SLRT) Project. A feasibility study that examined the application of SLRT to the connector project was completed in fall 1993 (Figure 5). Concurrently BART is examining the viability of a range of other applications.

BART's REGIONAL RAIL PLANNING PROCESS

Long-Term Implementation Planning

Developing the Bay Area regional rail system is a long-term venture. It has taken many years within the complex Bay Area

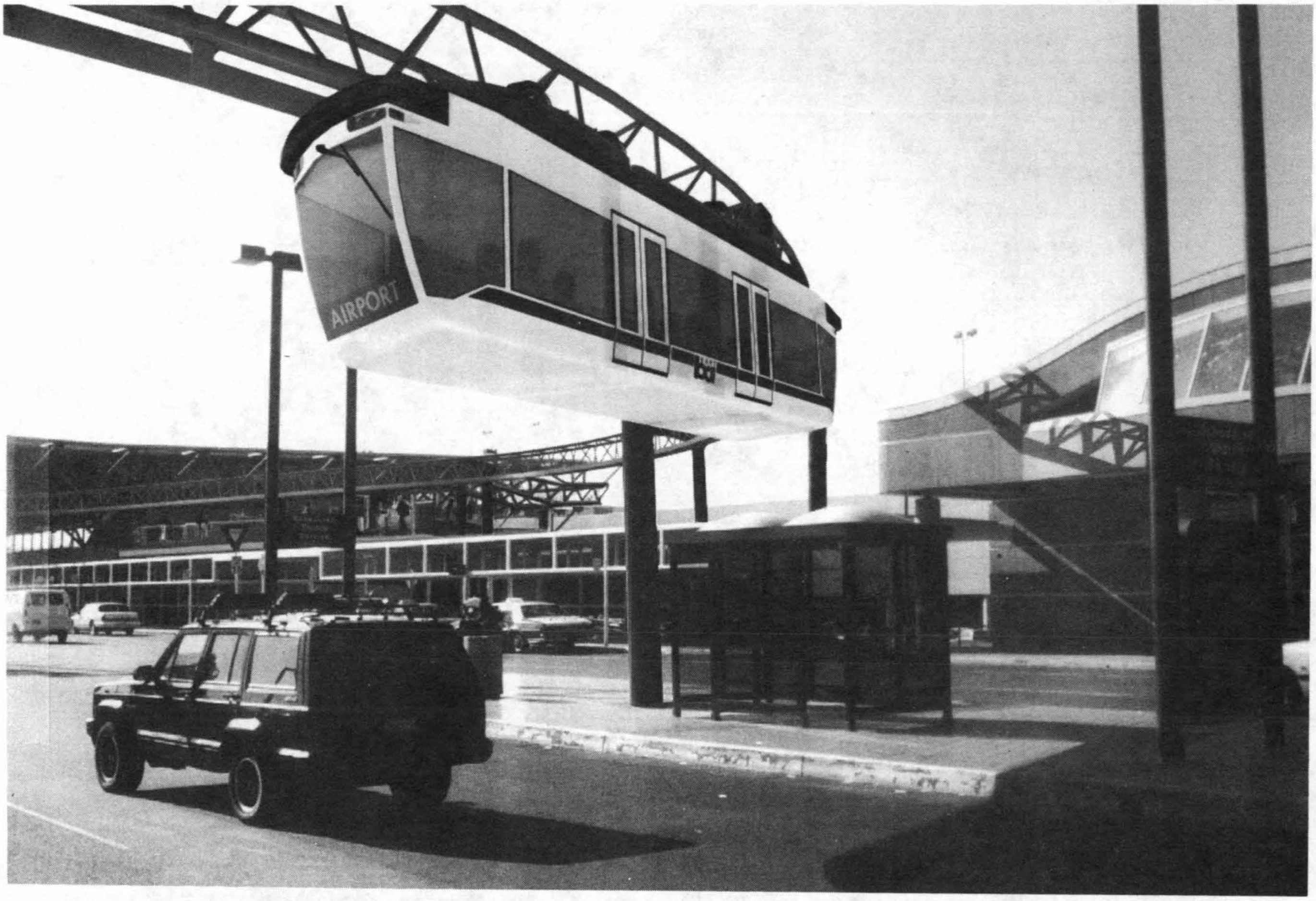

FIGURE 5 BART: Oakland Airport intermodal connector.

decision-making arena to develop consensus and fund the next generation of Phase 1 BART extensions. It will take many more years, possibly decades, before Phase 2 and 3 projects are developed. Although BART continues to advance these longer-term projects through implementation planning, recently adopted policy has refocused planning efforts on alternative modes. In addition, MTC is developing a financially constrained regional transportation plan (RTP) for the Bay Area that will affect funding opportunities for BART extensions. In response, BART recently identified a 200-mi commuter rail system that, consistent with the BART Extension Staging Policy, can provide interim regional rail service now while BART continues to pursue long-term planning and construction.

Implementation planning at BART is a long-term strategic approach to regional rail development. Its primary objectives are to accelerate long-range project implementation by improving project cost-effectiveness and community support. It achieves this by seeking immediate ways to lower future project costs and building future ridership by linking the corridor with the BART system through an interim mode of transit service. Existing needs and opportunities in the corridor shape the "evolution" of the project.

There are five major elements of BART implementation planning:

- Long-range planning studies,
- Community consensus,
- Early acquisition right of way,
- Interagency coordination, and
- Interim service.

BART has engaged in extensive implementation planning efforts for all of the East Bay extension projects over the past several decades.

Long-range planning studies for BART extensions were initiated soon after the BART system opened in the 1970s. Studies were completed for the Livermore-Pleasanton Extension, the Pittsburg-Antioch Extension, the San Francisco Airport Extension Project, the Oakland Airport Connector Project, the San Mateo County Extension, and a Southwest Corridor Extension in San Francisco. Subsequent studies were completed for the Warm Springs and West Contra Costa County Extensions in the 1980s. These studies, updated periodically to reflect land use and other changes, resulted in preferred mode, alignment, and general station locations for these projects.

All of these studies were completed with extensive community involvement. Most of the studies were completed with the participation of technical and policy advisory committees composed of staff and elected officials from affected communities. Extensive public meetings were held on most studies at major milestones, and many of the projects had citizen advisory committees. This community involvement continued through environmental clearance, design, and now construction on many of the projects.

In the early 1980s, BART adopted an Advance Right-of-Way Acquisition Program. A limited pool of funds was set aside, and all necessary extension rights of way were identified and ranked in terms of the need for preservation. Phase 1 station rights of way, for example, located in areas of rapid development were given a high priority. Advance right of way acquisitions from willing sellers were made for potential station sites and track alignment. These measures allowed BART to preserve viable station alternatives, thus ensuring that displacements at a future date would be minimized and future project costs reduced. It also allowed communities to engage in long-term station area planning, which in turn could improve future ridership and long-term cost-effectiveness.

Early project definition along with extensive interagency involvement has created many project development opportunities. On the Dublin-Pleasanton Extension, for example, it allowed for close coordination with the California Department of Transportation (Caltrans) in the early 1970s so that the widening in the Interstate 580 corridor could accommodate an 80-ft BART median for approximately 8 mi. This resulted in substantial cost savings. Close coordination with local jurisdictions has also afforded the opportunity to have potential station sites included in the general plan, thus allowing for long-range area planning before project implementation. BART continues to work closely with local jurisdictions and Caltrans to ensure that new highway improvements do not preclude subsequent BART construction.

Another essential element of long-term implementation planning is the provision of interim service in future extension corridors as a means of developing the ''transit habit'' and improving potential ridership. BART Express Bus service is operated in all of the future extension corridors. In addition, interim park-and-ride facilities have been constructed on BART-owned station sites.

Near-Term Interim Solutions

Despite its strong ''silver bullet'' train identity, over the past several decades BART has considered a variety of modes for possible implementation in extension corridors including bus, light rail, advanced light rail, and people-mover technologies. Last year, BART adopted a new policy regarding development and operation of the regional transit system. The district committed to ''continue functioning as the regional rail operator, to continue planning for multiple transit modes, and to expand its operations to nclude a fully integrated coordinated multimodal transit system.''

MTC is currently preparing an RTP. Described as a 20-year blueprint to guide Bay Area transportation investments, the RTP will divide projects into two tracks. Track 1 of the RTP will include only those projects for which existing sources of funds can be identified. Track 2 will include projects for which funding has not yet been identified and in essence will be used as an advocacy plan for new funding.

The MTC RTP process demonstrated that despite continued efforts by BART, new service in all of the BART Phase 2 and 3 extension corridors would be highly unlikely over the next 20 years. Consistent with new BART policy, BART developed the FasTrack, a staged approach to advancing the BART Extension Staging Policy within Track 1 of the RTP. It uses available funding sources and existing rail infrastructure to provide near-term interim commuter rail service in existing BART extension corridors.

BART's NEW FASTRAK PROGRAM

The FasTrak commuter rail program (Figure 6) will give the San Francisco Bay Area more than 200 mi of new passenger rail ser-

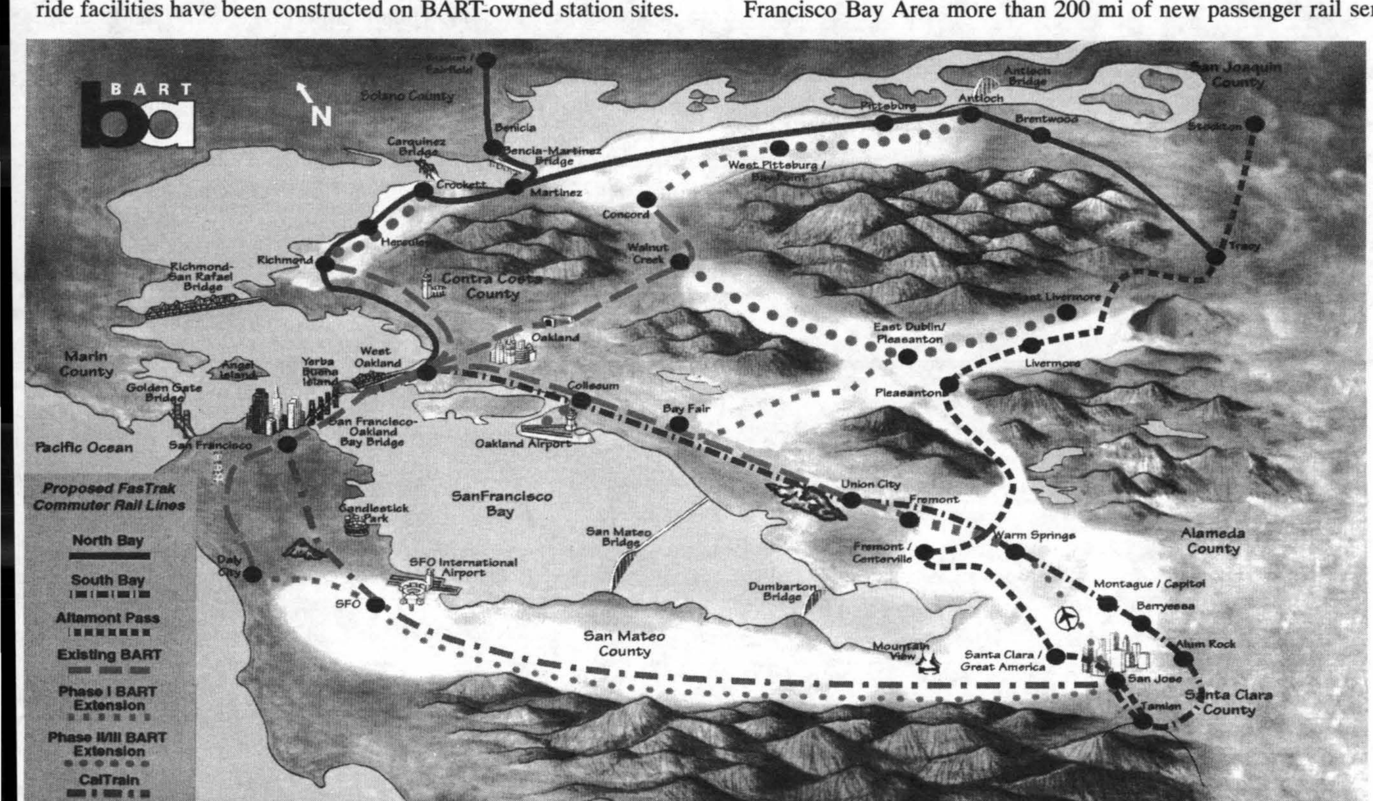

FIGURE 6 FasTrak regional rail map.

vice in three corridors: South Bay, North Bay and Altamont Pass. At an estimated cost of $100 million to $200 million, the regional commute system could be operational within 2 years, providing a reasonable commute alternative in Solano, Contra Costa, Alameda, San Joaquin, and Santa Clara counties for 3.5 million passengers a year.

South Bay Commuter Rail

The South Bay Commuter Rail line will provide service from the Cahill Station in San Jose to the existing BART station in West Oakland using the existing tracks of the Union Pacific Railroad. It will include 50 track mi and could serve up to 5,700 passengers a day. Intermodal links will provide easy access to BART, the new North Bay Commuter Rail, intercity rail, Caltrain, the Guadalupe rail system, the Tasman rail system, and the Oakland Airport Connector.

North Bay Commuter Rail

The North Bay Commuter Rail line will extend service along the Southern Pacific Railroad tracks to Brentwood in East Contra Costa County, with an additional line serving Fairfield and Suisun City in Solano County. It will include 77 mi of track between Brentwood, Fairfield, and West Oakland and could carry up to 6,400 passengers a day. Stations along the way will serve the communities of Antioch, Pittsburg, Martinez, Crockett, Hercules, and Richmond, providing easy access to BART, the new South Bay Commuter Rail, and intercity rail.

Altamont Pass Commuter Rail

The Altamont Pass Commuter Rail line will connect Stockton and Manteca with Livermore, Pleasanton, Fremont, Santa Clara, and San Jose using the existing tracks of the Union Pacific, Southern Pacific, and Joint Powers Board. The complete line will include 80 mi of track and could serve an estimated 1,400 passengers a day.

FasTrak offers multiple advantages:

- Alameda, Contra Costa, Santa Clara, San Francisco, and San Mateo counties will at last be linked in a fully integrated network of regional rail.
- An instantaneous regional rail network will be created: Intermodal Transit Stations will finally link all of the Bay Area's major transit systems in a single network.
- Commuter Rail will connect directly with the existing BART system, increasing BART ridership and helping the Bay Area develop its transit habit.
- Existing infrastructure and resources will be put to valuable and immediate public use.
- The Bay Area's regional rail system will evolve over time. Building on existing infrastructure and land use densities, it will be able to adapt and expand as conditions change and ridership grows.

CONCLUSION

Building a regional rail network takes decades. It has taken many years within the complex Bay Area decision-making arena to develop consensus and fund the next generation of BART extensions. Long-term implementation planning is an activity that is essential to achieving the long-term goals of the BART extension program.and to bring a regional rail system on-line today. It can lead to project acceleration by improving project cost-effectiveness and community support. It achieves this by seeking immediate ways to lower future project costs and to build future ridership by linking the corridor with the BART system through an interim mode of transit service. Service in an extension corridor can take many forms as it evolves over time. Existing needs and opportunities in the corridor shape the "evolution" of the project.

Publication of this paper sponsored by Committee on Rail Transit Systems.

Regional Rail: The Philadelphia Story

RONALD DEGRAW

The 323-mi regional rail network operated by the Southeastern Pennsylvania Transportation Authority plays a vital role in linking Philadelphia and its four suburban counties. With the opening of the Center City Commuter Connection in 1984, the stub-end rail lines operated by the former Pennsylvania Railroad and Reading Company were all through-routed into a truly regional service network. This is the largest unified regional rail network in North America. A line to Philadelphia International Airport opened in 1985, providing direct service to the new Pennsylvania Convention Center in downtown Philadelphia. The formation of the regional rail system is explained, along with the serious problems that contributed to ridership declines. Future route extensions are discussed, as is the transit authority's search for more practical and economical methods of operating rail service.

The regional rail network operated by the Southeastern Pennsylvania Transportation Authority (SEPTA) is one of the largest and most comprehensive in North America, operating 323 mi of lines and serving 160 stations in Philadelphia and the four adjacent suburban counties (Table 1). It is possible to board a train at any station in the 2,000-mi^2 area and ride to just about any other place. No longer is the rail network strictly a radial one, with all trains terminating in Center City Philadelphia.

The Philadelphia area's commuter rail lines were originally two distinctly separate systems built and owned by the Pennsylvania Railroad and the Reading Company. The earliest of the lines goes back to the 1830s, when the Philadelphia and Columbia Railroad was constructed westward from Philadelphia along the route of the old "Main Line of Public Works." All of the commuter lines were in operation by the end of the 19th century, when living in the suburbs and commuting to work by train was beginning to become popular. Both the Pennsylvania and the Reading established extensive commuter train service on most of the rail lines radiating from downtown Philadelphia. Both railroads built huge, impressive stub-end terminals within the shadow of City Hall. The Pennsylvania's Broad Street Station, originally built in 1881 and later expanded, was home to the railroad's general offices. In addition to commuter trains, the station played host to many New York and other long-distance trains.

Reading Terminal, at 12th and Market Streets, opened in 1893 and handled all of the Reading's trains, commuter as well as long distance. Both railroads electrified nearly all of their commuter service between 1915 and 1930, using multiple-unit equipment that survived into the SEPTA years. Because of the electrification, and the relatively high level of use, virtually all of the Philadelphia area's commuter lines remained in service, with few abandonments.

MID-CENTURY DECLINE AND RESCUE

Abandonments were minor, but much of the physical plant was permitted to decay. Ridership was dropping fast after the boom years of World War II, and expenses were rising even faster. This disastrous combination turned the commuter lines into high-volume losses by the late 1950s, and the railroads were as anxious to get out of the commuter business as they were to scrap long-distance passenger trains. Routine maintenance of stations all but ceased. Even such things as broken steps and burned-out light bulbs were often ignored. Lightly used trains were eliminated, and new commuter cars were not even seriously considered. Some of the equipment used on the Pennsylvania routes dated back to the original 1915 electrification of the Paoli line and was long past its time for retirement.

Southeastern Pennsylvania Transportation Authority, 714 Market Street, Philadelphia, Pa. 19106.

Decreased service and frequent delays and breakdowns resulted in more and more riders seeking alternative means of getting to work, usually turning to their automobiles. The Schuylkill Expressway from the west to Center City and the Route 309 Expressway from the north were both opened in the late 1950s, making driving to work more convenient and luring many riders from the trains.

It was under Philadelphia Mayor Richardson Dilworth in 1958 that the city began funneling subsidies to the two railroads to purchase improved service and some new cars. The subsidization program was successful in attracting additional riders, and so the subsidies grew; during the 1960s the four suburban counties began participating. Fares were reduced and kept low, service was reasonably good, and more new cars were bought.

SEPTA TAKES OVER

The initial modest subsidies eventually grew into millions of dollars a year, and when SEPTA was formed in 1964 it soon became the agency to oversee the commuter service and to administer the subsidy program. For the first 19 years of its life, SEPTA did not actually operate the railroad service. The Pennsylvania and the Reading continued to operate it with their employees, although SEPTA acquired ownership of most of the lines in 1976 and 1979 (Figure 1). SEPTA determined how much service would be operated and negotiated purchase-of-service contracts with the Reading and the Pennsylvania and later with Penn Central and then Conrail. Finally on January 1, 1983, by Congressional mandate, SEPTA began using its own employees to run the service.

Several long-distance lines, all operated with rail diesel cars because they were not electrified, were abandoned in 1981. Even though they operated for long distances outside of SEPTA's five-county service territory, they had never been subsidized by the other counties or states through which they ran. The excuse was also used that the RDC equipment was old and in need of major renovation. These lines ran to Bethlehem, Reading, and Pottsville, Pennsylvania; and Newark, New Jersey. Service on the nonelectrified Newtown line was suspended in 1983. In the following years service on a portion of an electrified line from Elwyn to West Chester was also suspended because the track needed major

TABLE 1 SEPTA Regional Rail System (February 1994)

ROUTE	DESTINATION	ONE WAY ROUTE MILES	AVERAGE WEEKDAY RIDERSHIP
R1	Phila. International Airport-Market East	9.7	2,200
	Warminster-Market East	20.1	*
R2	Wilmington-Market East	27.3	6,200
	Warminster-Market East	20.1	5,550
R3	Elwyn-Market East	15.5	8,300
	West Trenton-Market East	32.6	6,700
R5	Parkesburg-Market East	68.6	20,200
	Doylestown-Market East	34.2	9,600
R6	Cynwyd-Market East	6.6	250
	Norristown-Market East	18.1	4,300
R7	Trenton-Market East	35.0	7,750
	Chestnut Hill East-Market East	10.8	4,450
R8	Chestnut Hill West-Market East	13.3	5,850
	Fox Chase-Market East	11.1	3,350
	Total	323.0	84,700

* Shown under R2

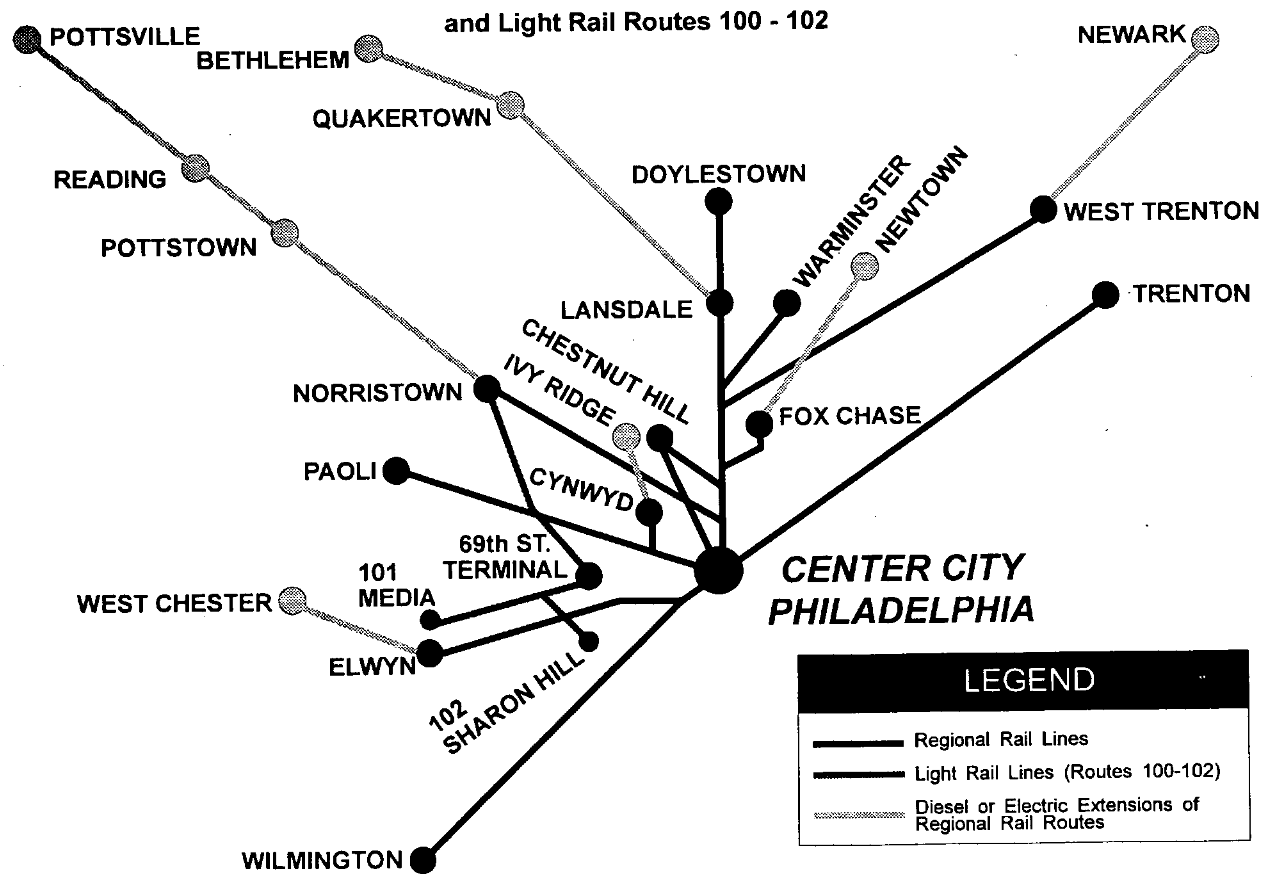

FIGURE 1 1980 regional rail system and light rail routes 100–102.

work and ridership was low. The West Chester and Newtown suspensions are technically temporary, although there is still no service there. SEPTA is currently attempting to accept a bid from a private operator to run the Newtown line.

CENTER CITY CONNECTION

The idea of connecting the two suburban commuter networks in the downtown area had been discussed for decades in Philadelphia. With private ownership of both lines, and a paucity of federal transit funds, the idea went nowhere. But the creation of SEPTA 30 years ago provided new impetus for the idea, with strong financial support from the city of Philadelphia.

The old Reading system deposited passengers two blocks east of City Hall, near the main department store district but several blocks from the principal office district. Furthermore, the office district was beginning to grow toward the west, even farther from the Reading Terminal. The Pennsylvania Railroad's underground Suburban Station, which replaced Broad Street Station as a terminus for commuter service in 1930, was much more centrally located to serve the prime business area but a good walk from most of the department stores. The Pennsylvania had the added advantage of a second stop for commuter trains at 30th Street Station, the main railroad station for long-distance trains on the west side of the Schuylkill River, near two of the city's largest universities.

To build an underground tunnel connecting the two railroad systems and inaugurate through service seemed to make a lot of sense. Serious planning for the tunnel got under way in the early 1960s. The project was dubbed the Center City Commuter Connection. Original discussions called for a six-track tunnel, but this was later scaled back to four tracks on a route parallel to and about a half block north of Market Street. Four of the seven stub-end tracks at Suburban Station were extended eastward in a tunnel from 16th Street to about 9th Street, where they turned sharply north and ramped up from the new tunnel to link up with the old Reading elevated right of way. A new station, called Market East Station, was constructed between 10th and 12th Streets in the tunnel to replace the old Reading Terminal. The new station was a part of the huge Gallery Shopping Complex built on the north side of Market Street from east of 9th Street to 11th Street.

COMMERCIAL AND OPERATING IMPACTS

All of the old and somewhat seedy buildings along Market Street were removed to make way for the Gallery complex, with the spacious new railroad station as its cornerstone. It is likely that the shopping complex could not have been funded without the proximity of the rail station, and it is probable that the rail station would never have been built without the commercial development. The entire project was basically an urban renewal program, and it went a long way toward improving the east side of Market Street, probably Philadelphia's most important commercial district.

The Center City Commuter Connection was one of the largest civil works projects in the nation, costing $330 million. When it opened on November 10, 1984, it changed forever the way the regional rail system was operated.

Now the SEPTA commuter rail network truly became a regional rail system (Figure 2). No longer was it simply a traditional group

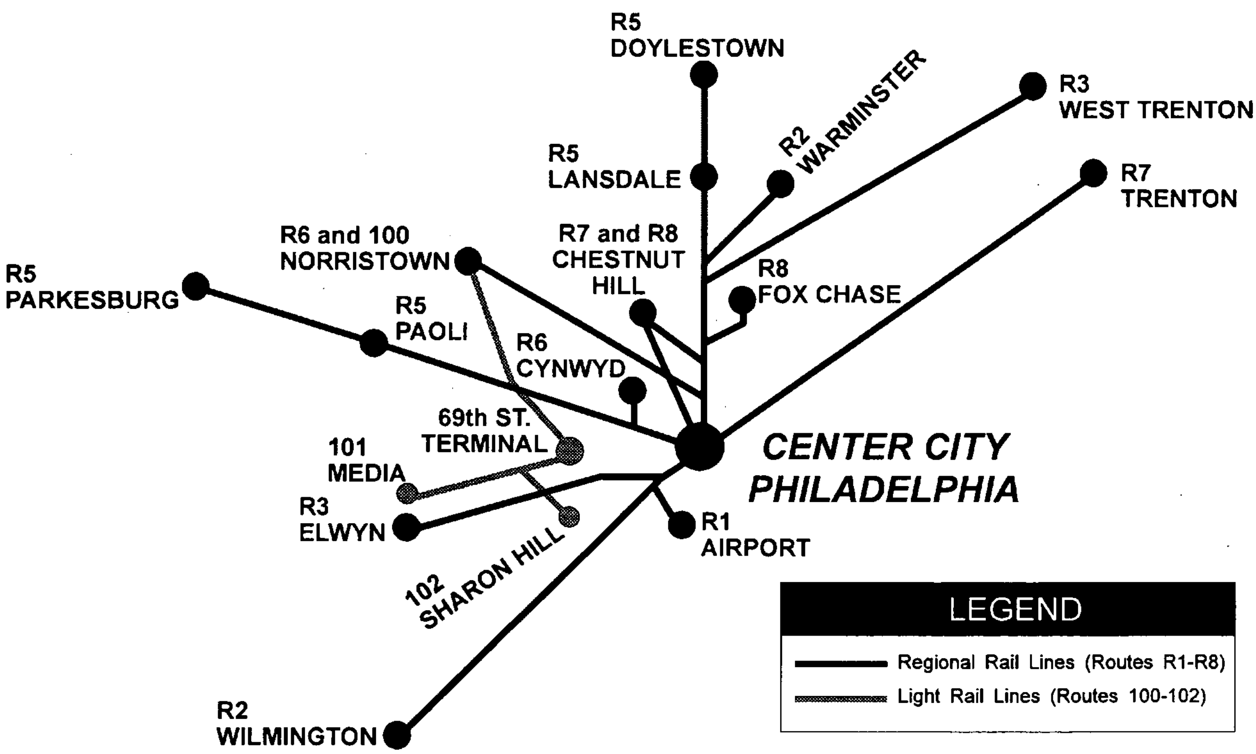

FIGURE 2 Current regional rail system and light rail routes 100–102.

of radial rail lines leading from the suburbs into Center City. Now all of the lines were through routed, each former Reading line linked with a former Pennsylvania line to form a single suburb-to-suburb via Center City routing. It became—and remains—the largest through-routed, truly regional rail network in North America.

This created some immediate operating changes, if not problems. Previously all trains dead-ended at a Center City station. If a train arrived late at Center City, its next outbound trip could often leave on time simply by reducing the train's layover time at the terminal. If a train was going to arrive at the terminal very late, its next trip could be filled by a relay train and crew on standby at the terminal. Train crews reported on and off at the terminal, making very simple such things as crew assignments and cash remittance. Now all of a sudden, a late-arriving train meant a late-leaving train, and some crews never spent any time at downtown stations. If trains on one branch fell late, it virtually guaranteed that trains on another branch would be late. On-time performance was suddenly much more important than previously, because a late train could now mean hundreds of people standing around on downtown station platforms. Great importance is therefore placed on running trains on time, and detailed daily records of each train are kept. The average on-time performance—which means less than 6 min late—is now about 93 percent.

SEPTA does not control the entire rail network, and so some decisions by other railroads unfortunately affect the on-time performance of SEPTA trains. Two relatively small portions of the system are owned by Conrail and are not generally much trouble. Three of the most important segments, however, are owned and dispatched by Amtrak, and SEPTA trains are often delayed while Amtrak trains are given priority or are delayed by slow orders on Amtrak trackage. These lines—all former Pennsylvania Railroad routes—run from Philadelphia to Wilmington, Trenton, and Paoli-Parkesburg. The Paoli line is SEPTA's most important route, with about 20,000 passengers daily.

IMPACTS ON PASSENGERS

When the Center City tunnel opened, passengers also immediately experienced a difference. At Suburban Station, passengers previously could board trains about 10 min before departure time. At Reading Terminal, the gates opened 5 min before a train left. Now at Market East Station and at Suburban Station, passengers stand on the platforms and wait for their trains to arrive the same as subway passengers do.

But the benefits of the through-routed system to passengers far outweighed the problems. Reading-side passengers could now travel to the western side of Center City at Suburban Station or make connections with an Amtrak train at 30th Street Station. The transfer between Reading Terminal and 30th Street Station was previously very awkward. And of course riders were now able to travel from one suburb to another, either without getting off in Center City or with an extremely easy transfer from one line to another at a downtown station. This type of traffic is growing, although very slowly.

It requires more cars to operate the through-routed service than it did to run the separate lines. A five-car train from Paoli to Philadelphia in the morning rush hour, for example, may next go north to Doylestown, even though the reverse-direction Doylestown service only requires a two-car train. No method of easily cutting and adding cars en route exists, and this is a major shortcoming of the Center City Commuter Connection.

TRAINS TO AIRPORT

A new rail line linking Philadelphia International Airport with Center City was opened in 1985 serving 30th Street Station, Suburban Station, and Market East Station. Two years ago the airport trains were extended northward to serve Jenkintown and the Warminster branch, opening up many more one-seat trip possibilities. The airport line operates every 30 min from 6:00 a.m. until midnight, but ridership has never exceeded 2,200 a day. Ridership has suffered from headways that may not be frequent enough and from the failure to build stations that were planned for Southwest Philadelphia and University City. The University City Station is finally scheduled to open in 1995. Crewmen on the airport line are specially trained to be able to answer questions about Center City hotels and tourist attractions, and the service has a high rate of reliability.

The opening of the new Pennsylvania Convention Center last year immediately adjacent to Market East Station is expected to result in additional riding on the regional rail lines, particularly on the airport line.

REDUCED RIDERSHIP

Ridership on the regional rail system is 84,000 a day, about the same as when SEPTA gained ownership of the lines 11 years ago but down 11,000 from the high of 4 years ago. Three major events helped to depress ridership. There was a 108-day strike of the railroad unions in 1983 as SEPTA sought—with ultimate success—to modify some of the existing work rules. The modifications helped to make the railroad operation more economically practical, but the long strike caused some people to permanently find an alternative means of transportation.

The economy took a major downturn a few years ago and is perhaps just now beginning to recover. In these years, however, many companies reduced the size of their work forces, which caused further deterioration in rail patronage.

And finally there was RailWorks. About a week after the long-awaited Center City Commuter Connection opened in 1984, it was discovered that the four-track Columbia Avenue bridge on the old Reading line just north of Center City was in imminent danger of collapsing. After years of planning and construction, after months of promoting the new tunnel connection, suddenly the entire Reading network was cut off from its connection to Center City. Reading-side passengers were temporarily transferred in North Philadelphia to Broad Street Subway trains, and SEPTA officials frantically patched together a plan to turn Market East Station into a temporary stub-end terminal for Pennsylvania-side trains. The bridge was rebuilt within 17 days, but it made a big impression on everyone involved. The deferred maintenance by the two private railroad companies in recent decades had not merely included stations and track. It had also included major safety items such as bridges. SEPTA quickly found that many of the two dozen bridges on the Reading between Center City and Wayne Junction were in poor shape and would soon need to be rebuilt or closed. Fearing another major service disruption, SEPTA put together a mammoth $264 million project to rebuild all of the bridges on this 2-mi segment. The project was called RailWorks, and it meant closing the Reading-side connection to Center City for 6 months in 1992 and another 4 months in 1993. Passengers transferred to the Broad Street subway to complete their trip downtown. The project was a great success, finishing on time and under budget, but the lengthy service disruptions drove away many passengers, some of whom never returned.

PLANS TO REBUILD PATRONAGE

The challenge for the future for SEPTA's regional rail lines is to recapture ridership through better service and reliability, faster trains, feeder buses, more parking spaces, reasonably priced fares, and expansion of service into new areas.

Many of these goals have already been tackled. Some lines now have more express trains and later night service than they had before SEPTA acquired the rail lines a decade ago. There have been some minor improvements in speed, but much more work needs to be done in this area to make the trains competitive with automobiles on the expressways.

About 5 years ago SEPTA began creating special bus routes dedicated to meeting trains and shuttling passengers to industrial parks and shopping centers. These routes have met with moderate success. Thousands of parking spaces have been added, with many more proposed for the near future. Most passengers now use weekly or monthly passes, which provide substantial discounts over regular cash fares.

PROSPECTS FOR EXPANDED SERVICES

Expansion of the system in several directions is being considered (Figure 3). The first restoration of previously discontinued rail service may be the branch from Fox Chase to Newtown, which is not electrified. Service ceased a decade ago, and may be restored in 1995 by a private contractor operating European diesel cars that would connect with SEPTA electric trains at Fox Chase.

The same contractor is examining the possibility of operating diesel cars over the nonelectric portion of the old Bethlehem branch from Hellertown to Lansdale, where connections would be made with existing SEPTA train service. Both the Newtown line and a portion of the Bethlehem line are in SEPTA's capital program for restoration of rail service at some future time, but service may be resumed sooner if the private operator is successful.

SEPTA is examining the practicability of restoring rail service between Elwyn and West Chester, an electrified branch that saw its last trains in 1985. The option of operating this as a light rail line with frequent service, including 20-min peak trains, is being considered. The reduced costs of operating the branch as light rail instead of commuter rail could result in the ability to offer a much greater frequency of service.

Also under discussion is the possibility of restoring service from Norristown to Pottstown and perhaps Reading. This is also nonelectrified territory, which operates a high density of Conrail freight trains. It was the old main line of the Reading Company, and passenger service was eliminated in 1981.

It has often been suggested that SEPTA take over the 104-mi Philadelphia-to-Harrisburg line from Amtrak, which has been re-

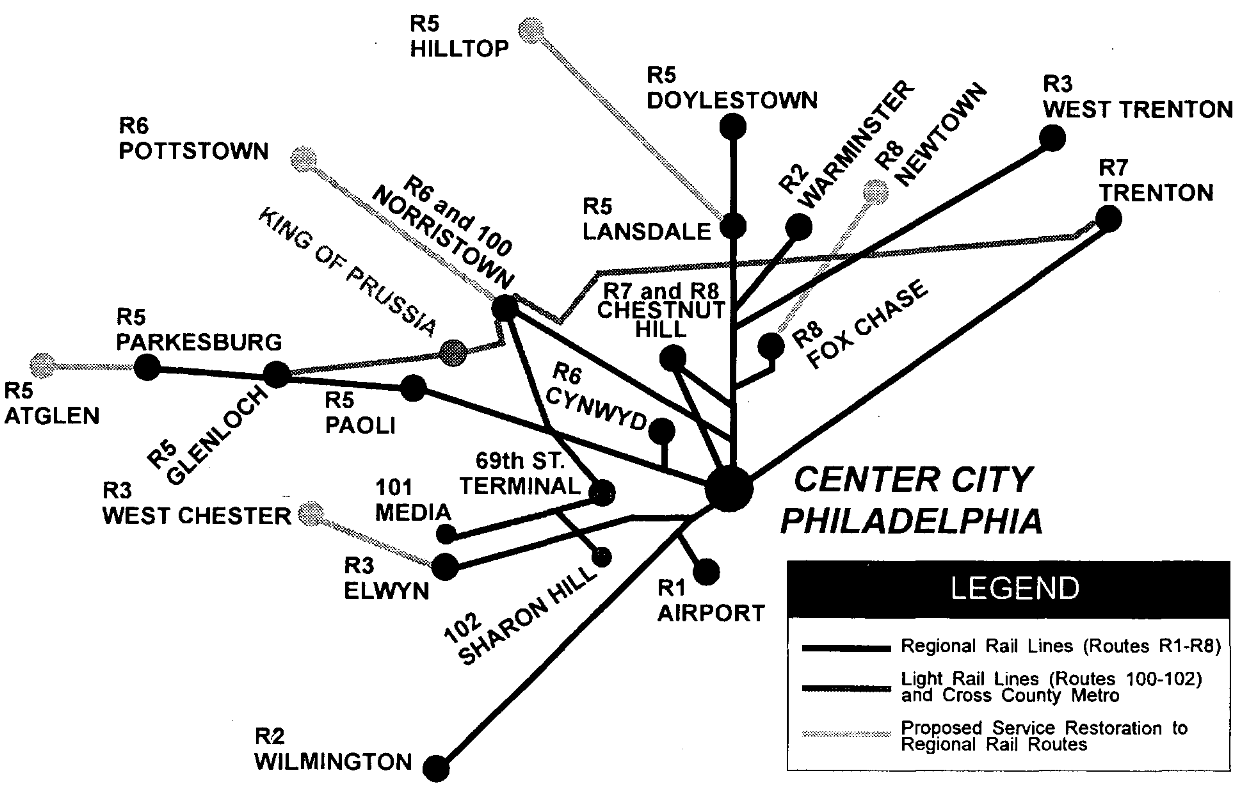

FIGURE 3 Proposed Cross County Metro and proposed service restorations, with current regional rail system and light rail routes 100–102.

ducing service in recent years. SEPTA trains already run 44 mi out the Harrisburg line to Parkesburg.

The most unusual proposal for new service may also be the most promising. SEPTA is seriously considering instituting passenger service on the old Pennsylvania Railroad's Trenton Cut-Off line, which runs from Morrisville west to Downingtown, where it connects with SEPTA's Route R5 Parkesburg line. Dubbed the Cross County Metro, this line crosses several SEPTA bus and rail routes and would offer an interesting opportunity to provide circumferential rather than strictly radial journeys.

The biggest problem facing all transit authorities today is the rapidly changing habits of workers. Not too long ago, nearly all jobs were in the city, most of them in the downtown area, so radial transit routes—both bus and rail—made a lot of sense and served the needs of their customers very well. Today those job patterns have changed dramatically, with far more people living in one suburb and commuting—usually by automobile—to jobs in another suburb. This radical change in commuting habits has been an incredible challenge to transit agencies, and one which has been almost impossible to cope with successfully. SEPTA and other agencies have established many cross-county bus routes, but they are usually slow and meandering and fail to attract a great many riders. The Cross County Metro, on the other hand, would be a high-speed rail line designed to provide easy access from one suburb to another, with transferring from connecting radial routes. It may even be possible to through route trains down a portion of an existing radial route and then over part of the Cross County Metro for an even faster ride.

SEARCH FOR OPERATING ECONOMIES

The regional rail system is extremely expensive to operate, with revenue meeting only 39 percent of expenses, and SEPTA is searching for more economical methods of conducting rail passenger service. A number of options will be examined in the near future, including the possibility of high-level platforms for faster loading and unloading, prepaid fares to reduce the number of onboard staff, a greater number of express trains combined with faster running times, and the possibility of running "metro" type service or even light rail operation on some of the lines, segregating them from the rest of the system so that they can operate under standard rapid transit or light rail operating rules rather than under railroad rules.

Many of the lines have passenger volumes and characteristics that may justify conversion to light rail, which would be cheaper to operate and could therefore run more frequently and attract more passengers.

There is a tremendous investment in the Philadelphia region's rail commuter network, and because of its size and vast coverage the potential for future improvements and ridership increases seems virtually unlimited. With the huge RailWorks improvement project now completed, SEPTA will be attempting to make whatever modifications are practical to serve the commuting trends of the 21st century and to increase its ridership.

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PART 4

Light Rail

Comparative Evaluation of Performance of International Light Rail Systems

WILLIAM M. LYONS, EDWARD WEINER, AND PAUL SHADLE

Findings are presented from an analysis of the performance of international light rail transit (LRT) systems, conducted by the Urban Transport Group of the European Conference of Ministers of Transport (ECMT). The analysis is based on case studies and national overviews provided by the six participating countries (France, Germany, the Netherlands, Switzerland, the United Kingdom, and the United States), which are included in the detailed ECMT report. The project traced LRT development; reviewed policy, managerial, and technological trends; and analyzed comparative cost-effectiveness. Policy conclusions reflect the consensus of the six national delegations. Standardized financial and operational data, as developed for the study and applied in a balanced set of performance measures, are difficult to define for international systems. Nevertheless, efforts such as this encourage an objective exchange on international experiences with different public policies and operational approaches. The standardized framework developed for the project allowed consistent comparisons of the international systems. The seven systems evaluated were publicly operated, but several included private involvement, ranging from private equity shares in Nantes and Grenoble, France, to the turnkey approach in Manchester, England. The governments sponsoring LRT in the case study cities set broad goals, ranging from attracting automobile drivers and improving air quality to reducing congestion while recovering costs. Even though success was often not quantified, the governments were generally satisfied with results. All countries conducted some analysis of alternatives before selecting LRT, but analysis was less comprehensive and rigorous than might, for example, be expected of major investments under the requirements of the Intermodal Surface Transportation Efficiency Act.

In recent years there has been an upsurge of interest in member countries of the European Conference of Ministers of Transport (ECMT) in building new urban light rail transit (LRT) systems and extensions to existing ones. Many urban areas that did not have the size and density for conventional heavy urban rail systems have considered LRT as an attractive alternative. LRT systems are less expensive than heavy metro systems but nevertheless entail substantial transportation investments for urban areas and the organizations that finance them.

National and local governments are, therefore, concerned about the appropriate role of LRT systems in providing transportation in urban areas (as well as other concerns related to the environment and livability of these areas). They are interested in the economic performance of these systems and the factors and conditions that affect that performance. In light of this current interest in LRT, the Urban Transport Coordinating Group of the ECMT carried out a detailed study with the following objectives:

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1. Tracing the development of LRT in ECMT participating countries;
2. Reviewing current LRT trends in policy, managerial, and technological innovations;
3. Identifying current economic, financial, and broader social policy issues and concerns related to LRT, including environmental, safety, congestion relief, and urban structure;
4. Analyzing the cost-effectiveness of light rail systems in the context of broader social policy issues and concerns; and
5. Identifying conditions that affect the economic performance of LRT.

Information for this study was obtained from the six participating countries: France, Germany, the Netherlands, Switzerland, the United Kingdom, and the United States. Each country prepared an overview of its existing and proposed light rail systems. These were supplemented from other data sources, including the International Union of Public Transport, which also participated in the project (*1*). Each country also analyzed one or two of its own new LRT systems using a consistent framework that standardized methodologies and data to be evaluated. The framework allowed the comparison of results and a synthesis of findings and conclusions based on international experiences. In addition, the work group discussed policy issues and their implications and reached related conclusions by consensus based on national experiences.

The results of these analyses have been synthesized into a detailed report to be presented to the transportation ministers of the ECMT countries (*2*). This paper summarizes some of the most important analyses and findings of the research and focuses on the third and fourth objectives listed earlier: comparative analysis of cost-effectiveness and discussion of policy issues.

DEFINITION OF LRT AND RECENT DEVELOPMENTS

Defining LRT can be a matter of controversy in the international public transportation industry. For the purposes of the ECMT report, a flexible definition was applied. The definitions used were provided by TRB's Light Rail Transit Committee, which defines light rail as

> a metropolitan electric railway system characterized by its ability to operate single cars or short trains along exclusive rights of way at ground level, on aerial structures, in subways, or occasionally, in streets, and to board and discharge passengers at track or car floor level.

This definition allows older tram systems, even those operating primarily in mixed traffic with no grade separation, to be included in this study.

In the six countries participating in this study, LRT systems have enjoyed strong support the past 15 years. Most large cities in the former West Germany never abandoned their tram systems and in the 1960s began to upgrade them to full LRT by resurfacing surface street lanes for trams, building tunnels, buying large capacity vehicles, and integrating them with other modes. Trams have remained popular in the former East Germany but generally have not been upgraded and will require substantial new investment.

Trams had passed into virtual extinction in France and the United Kingdom by the early 1970s, but by the end of the decade LRT was receiving new attention. Since then new French systems have been built in Grenoble, Nantes, and Paris, and a new British system opened in Manchester. Additional urban LRT is planned or proposed in both countries. The British seek to route LRT on underused railroad rights of way, whereas the French design their systems to be the focus of urban development.

After declining to seven systems in the 1970s, LRT in the United States enjoyed a resurgence beginning in the 1980s. Old systems were reconstructed or extended, and new lines were opened beginning with the San Diego Trolley in 1981. Between 1980 and 1993 LRT systems in the United States more than doubled, from 7 to 15, and additional service is being considered in many other cities.

Trams have continued to operate in several large cities in the Netherlands. Since the late 1970s the Dutch government has regarded LRT as one solution to the transportation needs of smaller "satellite" cities. In Switzerland trams remain in five large cities and many electrically powered regional light rail lines operate throughout the country. Many of the regional lines have been modernized with light rail vehicles, and a completely new LRT system recently opened in Lausanne.

EVALUATION AND COMPARISON OF PERFORMANCE

This section evaluates the performance of the LRT systems included in the case studies: Grenoble and Nantes, France; Stuttgart and Hannover, Germany; Nieuwegein (Utrecht), the Netherlands; Bern, Switzerland; and San Diego. Information is also included from Manchester, although actual operational data were not available from this new system. Each system studied is expected to achieve broad goals ranging from improving mobility, to decreasing congestion, to recovering costs from fares. To compare the overall performance of the LRT, this section evaluates standardized data on benefits, costs, and service. The reporting framework established a rigorously defined standard set of comparable performance data for the participating countries.

Given differences in the completeness and underlying assumptions of data provided by public transit authorities, performance measures should be used with caution to compare LRT. To prevent distorted assessments, the measures should be reviewed together rather than as separate components. For example, an emphasis on operating costs that excludes consideration of capital costs will bias comparisons in favor of systems that have low operating costs, such as some that rely heavily on automation. The following analysis clarifies assumptions and data differences where possible and draws a number of conclusions about relative performance. Other analysts may apply their own assumptions to the data provided (for example, choosing different asset lives and discount rates) to make system comparisons.

Because currencies and the time periods during which LRT investments were made differ, cost figures obtained were adjusted. To derive comparable capital costs for new systems or extensions, figures reported by the different LRT operators were converted into dollars based on International Monetary Fund exchange rates. These nominal dollars were then converted into constant 1990 dollars based on an index of U.S. gross national product growth from 1950 to 1990. The resulting figures provide a reasonable estimate of total capital expenditures. Using a standard capital recovery factor that assumes asset lives of 20 years for vehicles, 40 years for construction, and infinity for rights of way, the 1990 capital investments were annualized. The capital recovery factor was derived using the formula $i/[(1 + i)^n - 1] + i$, where i equals the discount rate, which is 8 percent, and n equals years of asset life. An 8 percent discount rate was used because it falls roughly between the 10 percent rate used by the U.S. Office of Management and Budget and the lower rates used by European nations. The quality of the cost estimates is dependent on the data—more disaggregate data would improve comparisons.

The intent of the performance analysis is not to rank transit systems by performance measures but to evaluate relative performance using a balanced set of measures. It is probable that relative performance will change over time, and is sensitive to the assumptions used. It was not possible to test the degree of sensitivity of the different assumptions, for example, use of an 8 percent discount rate or different currency exchange rates.

Total capital cost figures allow a rough comparison of the magnitude of investment in the different LRT systems. Although data provided was of varying degrees of completeness, the figures illuminate some interesting differences. Costs from Grenoble, Nantes, and San Diego were separated for right of way, construction, and vehicles; total reported costs for their projects (all figures are in 1990 dollars) were $400 million, $129 million, and $346 million, respectively. Bern reported expenditures between 1956 and 1990 for construction and vehicles totaling $237 million. Nieuwegein listed expenditures in 1983 for construction and vehicles totaling $100 million. Hannover and Stuttgart reported uncategorized total annual depreciation costs for their light rail transit systems of $15 million and $16 million, respectively, which were assumed to reflect their annualized capital costs but not total capital investments.

The older systems, reporting no right-of-way costs (Hannover, Stuttgart, and Bern), could be assumed to have been given their rights of way; the value of the existing right of way might conceivably be estimated, but this was not done for this project. These systems are upgrades, in contrast to the others, which are new starts (Grenoble, Nantes, Nieuwegein, and San Diego). Also note that the French systems are urban and run over street-based track, which does not involve purchases of right of way, as do the more suburban systems. Because the approach to right-of-way costs is so different among the systems, right of way was separated from other capital costs (Figure 1).

Estimated annual capital costs were used to compare the effectiveness and efficiency of use of capital per: passenger kilometer, vehicle revenue kilometer, and unlinked trip. Low annualized capital unit costs indicate either intense use of capital in the form of heavy ridership or well-planned, efficient investments.

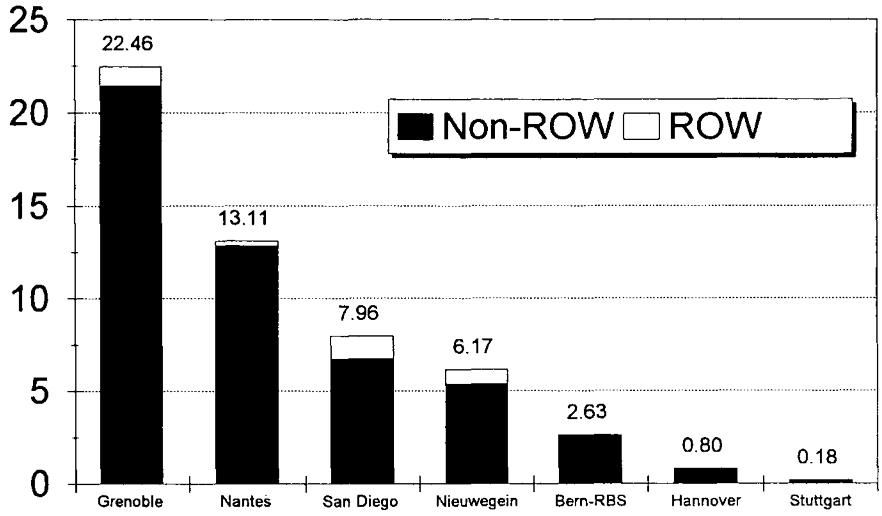

FIGURE 1 Annual capital costs ($/vehicle-revenue-km).

Conversely, high capital unit costs may suggest low ridership or relatively expensive investments. In the definition of vehicle kilometers, two or more sections that are connected by an articulated area are considered as one vehicle. Two or more separate units coupled without connecting articulation are considered separate vehicles, even if the coupling is semipermanent.

A number of efficiency and cost-effectiveness performance measures are calculated for each system, and the policies of each are analyzed. Tables 1 and 2 present the data from which the 11 quantitative performance measures in the figures are derived.

Capital costs per trip suggest that Nantes ($0.79) and Nieuwegein ($1.24) have low capital costs relative to those in San Diego ($2.70). Per trip costs, however, tend to be low on systems with short average trip lengths, such as Nieuwegein. More neutral costs per vehicle revenue kilometer (Figure 1) indicate that Nantes ($13.11) and Grenoble ($22.46) have relatively high capital costs. San Diego ($7.96) uses capital effectively according to this measure. Stuttgart ($0.18), Hannover ($0.80), and Bern ($2.63) indicate relatively modest costs per vehicle kilometer, but their costs appear comparatively low because of the absence of reported right-of-way expenditures.

Passenger kilometer data were incomplete, but the figures provided indicate that ridership is relatively heavy in Bern and Nieuwegein (Table 1). When 1989 capital and operating costs are combined (Figure 2), Grenoble's costs per kilometer are high ($27.99) and San Diego's are lower ($10.37), whereas those of the cities not reporting right-of-way costs appear comparatively low.

Operating costs alone offer a consistent means of comparing cost-effectiveness, measured in cost per unit of service, and cost-efficiency, measured in cost per unit of service consumed (ridership). The expenditures per trip suggest that the French and Dutch systems are relatively inexpensive, whereas those in Germany, Switzerland, and the United States are more costly. However, costs per trip are affected by differences in average trip length (Figure 3), which vary widely depending on system characteristics—for example, whether they provide shorter urban trips (Grenoble and Nantes) or longer more suburban trips (Bern, San Diego, and Nieuwegein).

Operating costs per vehicle kilometer and passenger kilometer (Figure 4) suggest that San Diego, where average trips are long, and Nieuwegein provide relatively cost-efficient and effective LRT service.

Financial performance measures indicate whether some of the systems have achieved fare recovery targets. The San Diego Trolley recovered 92 percent of operating costs through fares, substantially more than other American LRT systems. In France, re-

TABLE 1 Background Data

	Opened	Population (000)	Operating Costs ($000)	Revenues Fares ($000)	Subsidies Total ($000)	Other Income ($000)	Train Intervals Peak	Peak Vehicle
Bern-RBS	1899	190	29059	15735	5139	8185	15	60
Grenoble (1988)	1987	362	5277	19240	17957		4/2	21
Hannover	1883	1050	72804	60666			8/12	
Manchester	1992	2600						
Nantes (1988)	1985	464	4116	22721	24371		5	28
Nieuwegein	1977	230	4255				8	24
San Diego	1980	1704	9159	8732	1787	53	7-15	45
Stuttgart	1868	1600	98270	73549			6/10	

TABLE 2 Operating Data

	Speed (KM/HR)	Veh. Rev KM (000)	Veh. Rev. Hours (000)	Pass. Trips Unlinked (000)	Passenger Km (000)	Route KM Total	Staff
Bern-RBS	37	8366	227	17500	168100	63	353
Grenoble (1988)	18	955	53	16500	35049	9	59
Hannover	24	18336	752	96501	476736	192	2414
Manchester							
Nantes (1988)	22	873	40	14500	24008	13	81
Nieuwegein	29	1768	45	8685	59053	18	
San Diego	30	3808	126	11217	122182	53	148
Stuttgart	22	36726	1454	94383	495801	110	3156

covery rates for all transit modes increased after LRT service began. More impressively, 1988 operating revenues in Grenoble for LRT service exceeded costs by 29 percent. In contrast, Stuttgart and Hannover had recovery rates of 66 and 70 percent, and Hannover's rate had fallen from 78 percent in 1985. However, in both German cities LRT costs per passenger and vehicle kilometer are lower than for buses, suggesting the relative success of investment in LRT. The Bern system reported a 72 percent recovery rate. Note that all of these figures exclude capital costs. This comparative analysis would improve with information on how and at what level fares are set in different cities to achieve targeted cost recovery rates.

Combined capital and operating cost figures allow a more complete comparison of service effectiveness and efficiency. Because data on passenger kilometers are not collected in all the countries studied, only a limited comparison of cost-effectiveness is possible. Combined costs per vehicle kilometer and passenger trip, however, suggest a range of efficiency (Figures 2 and 5). Grenoble's combined costs are high per vehicle kilometer and trip, whereas these costs are consistently low in the German cities. As expected, all costs are lower on improved or extended LRT routes (Stuttgart and Hannover) than on entirely new systems (Grenoble and San Diego). Long trips (San Diego and Bern) also result in higher combined costs than short trips (Stuttgart, Nantes, and Hannover), making it difficult to rely on this indicator for comparison.

The systems studied reported different LRT impacts on ridership. On the San Diego Trolley, boardings per vehicle kilometer increased by 23 percent between the first year of operation and 1988–1989, and a 1985 survey indicated that 48 percent of riders had previously traveled by car. In Nantes 18 percent of LRT riders were new to public transit and 17 percent formerly traveled by car. Trips also grew by 31 percent between 1984 and 1987, while cost per passenger kilometer was lower than for buses; by 1989 public transit accounted for a lower proportion of total trips than in 1980. Twelve percent of riders were new to public transit in Grenoble in 1988, where LRT accounted for 30 percent of all transit trips.

Total rail trips grew in Hannover and Stuttgart after LRT was improved, although ridership in Hannover actually dropped between 1985 and 1989. Nieuwegein identifies 23 percent of its 1984 riders as new to LRT and 8 percent as former automobile drivers. Bern decreased one-way and commuter subscription fares in 1987, resulting in increased ridership and costs, decreased receipts per passenger, and a larger operating deficit. However, tran-

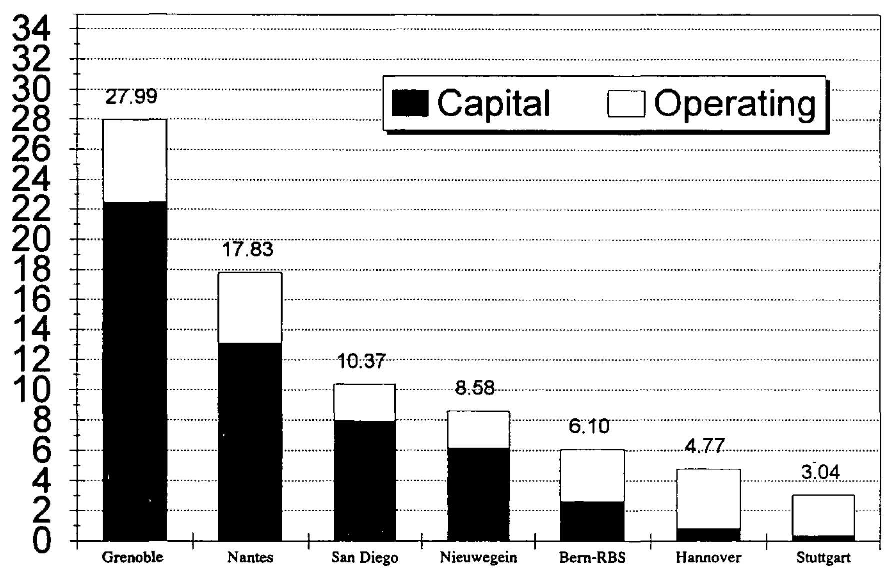

FIGURE 2 Operating and capital costs ($/vehicle-revenue-km).

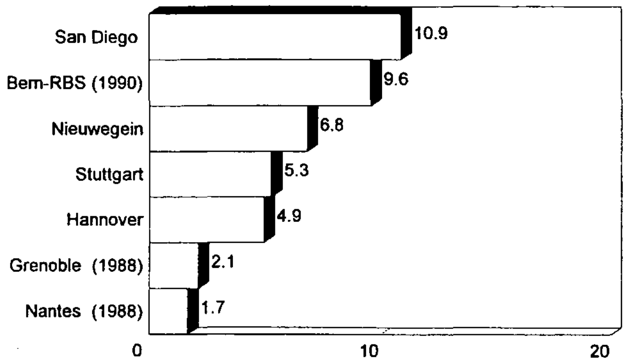

FIGURE 3 Average trip length (passenger-km/unlinked trip).

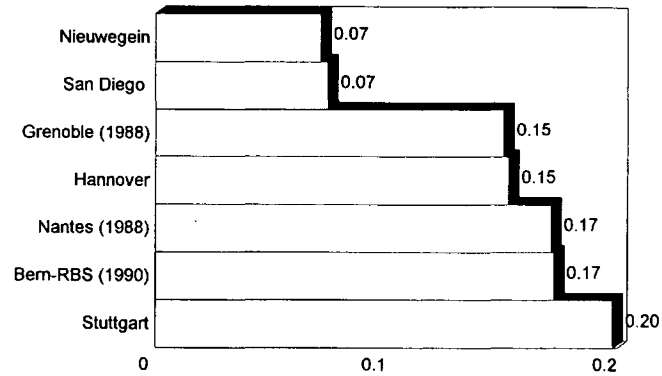

FIGURE 4 Operating expense per passenger kilometer ($/passenger-km).

sit ridership in Bern-RBS grew from 15 million to 18.3 million between 1987 and 1991, and automobile traffic on the Bernstrasse has actually declined since 1985. Bern-RBS has integrated its LRT lines with a system of feeder buses and timed transfers. Better data on total automobile use, trip times, and emissions would indicate how well LRT has discouraged automobile travel and reduced congestion and air pollution in all of these cities.

Load factors (average car loads) also provide some measure of how service outputs and ridership are linked. Although the data for this indicator are imperfect because some systems provide loads for their entire rail systems, the information still is informative. Nieuwegein and San Diego reported more than 30 passengers per vehicle kilometer. This is notable in San Diego, where average trips are quite long and capacity appears to be heavily utilized. Stuttgart and Hannover also report respectable load factors—27 and 26, respectively—but this is for LRT combined with other modes.

Average speed is an important factor in system efficiency. The fastest systems, San Diego and Nieuwegein, also have the lowest costs per hour. These two systems, along with Bern-RBS, are generally suburban and operate on reserved rights of way, which increases speed relative to the more urban systems, Nantes and Grenoble.

POLICY ANALYSIS

In this section the planning and management policies that have guided the development of the LRT systems are analyzed. The analysis is based on the case studies, national overviews, and discussions among the national delegations on policy issues and implications. Conclusions reflect the consensus of the delegations.

Expectations and Results

Reasons for building LRT systems are similar but vary somewhat by location. Many U.S. cities are experiencing rapid growth in automobile trips and declining use of transit service, causing congestion and air pollution. European cities such as Grenoble and Hannover face growing automobile travel and intense use of public transit facilities that are wearing out or, in the case of bus systems, increasingly in conflict with automobiles. All cities studied have strained financial resources. LRT systems are intended to offer large numbers of passengers convenient transit that supplements and is more rapid than buses but that is less expensive to build and operate than metro. In most cases LRT and buses were planned as parts of an integrated system.

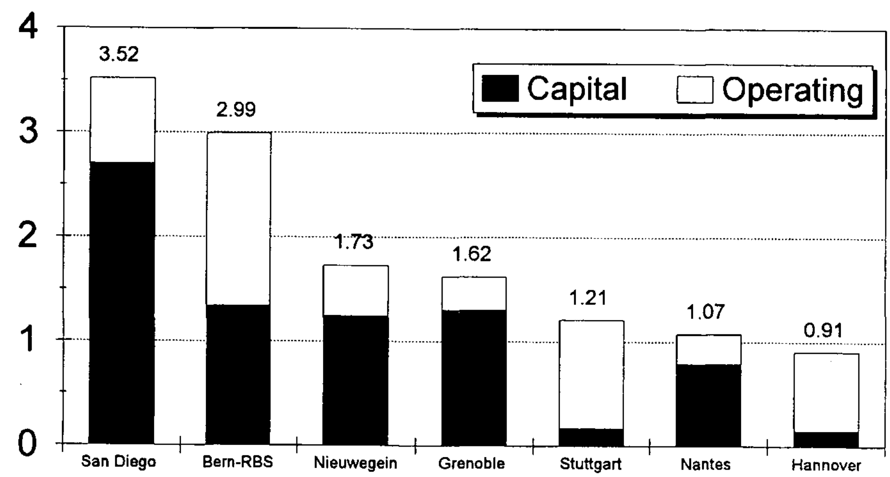

FIGURE 5 Operating and capital costs ($/unlinked passenger trip).

New LRT systems are expected to carry passengers who might otherwise travel by automobile or bus, or not at all. As stated by the Grenoble operator, these systems may positively alter "the quality and fabric of city life." Goals range from increased public transit use, reduced automobile and bus use, and reduced congestion and air pollution to improved mobility for those with disabilities. Passengers are often drawn from peripheral bus routes and automobiles and channeled onto LRT, easing traffic in central cities. The service is considered socially and environmentally attractive because it runs on largely segregated rights of way that reduce the conflict and delay caused by buses, entails a less disruptive construction process than metros or highways, and, if well-integrated with other modes, is attractive and accommodating to riders. Reduced congestion, combined with reliance on vehicles that use electricity rather than directly burning fossil fuel, should also improve air quality. Not least important, LRT offers the possibility of low capital costs relative to metro projects and low operating costs relative to bus and some other transit options.

Each system seeks to maximize fare recovery and ridership. These goals are difficult to achieve simultaneously: low fares might attract new riders but can reduce revenue, and high fares can deter riders. More frequent service, convenient access, and careful routing are alternatives to pricing that may induce ridership and allow reasonable fares. Given the external benefits expected from LRT use, some costs may be covered through subsidies, depending on federal, state, or local policy.

All of the cities studied stated that LRT has met most expectations and achieved high levels of service and ridership. Though the data are sparse, cost and ridership information suggests how well LRT systems have performed. For example, after LRT was added to an exclusive bus system in Grenoble, vehicle kilometers and ridership grew while expenditures declined and cost recovery improved, suggesting that the new investment met major objectives. Bern-RBS reports that automobile traffic on the local Bernstrasse actually declined after LRT service was modernized. San Diego, Nantes, and Nieuwegein identify many of their LRT users as former drivers. Manchester is evaluating travel patterns and road congestion to assess whether expected LRT benefits have been achieved.

Project Selection Methodologies

Project selection methodologies, such as alternatives analysis, whether superficial or comprehensive, are fundamental to decisions about whether to build LRT systems. Planners and policy makers seek to build cost-effective transportation systems and therefore should evaluate a range of alternatives. In each country studied, some alternative analysis was required and performed, but approaches differed. Incomplete responses from participants in the study and data limitations preclude a detailed review of the various analyses. For example, it is not possible to determine which criteria were used to assess the relative values of project benefits and costs. And project economic lives and discount rates applied in analyses were not identified.

The data do suggest limited conclusions about the extent of alternatives analysis in the different countries. Analyses range from assessments of strict financial benefits and costs to assessments of broader benefits and costs related to urban design, air pollution, travel times, and other more complex factors. Population and transit use projections do not appear to be conducted routinely, and it is not clear that environmental impacts and the value of time are consistently calculated. Estimates of LRT's potential to divert travel from private to public transit are crucial, but sometimes they appeared to be done after instead of before the new systems were installed.

Analysis of benefits and costs is often overwhelmed by other issues. LRT systems are sometimes selected as the mode providing more capacity than buses at lower cost than heavy rail or metro systems rather than on the basis of more thorough analysis.

Britain requires extensive alternatives analysis before government funding, which provides an incentive for the development of cost-effective systems. Public projects must demonstrate that their future benefits will exceed costs. Fares must be designed to recover costs from beneficiaries, usually defined as riders. A demonstration of benefits to nonusers, however, may serve as the basis for grants from the British government to meet revenue shortfalls. This method encourages cost control and imposes discipline on selection. Consideration of many alternatives can lead to the discovery of options for meeting transportation needs not previously considered. Such a process rationalizes expectations, reduces waste, and promotes accountability.

Before LRT was explored in Manchester, three alternatives for linking commuter rail lines that terminate in the central city were rejected by the national government because costs exceeded benefits. Once LRT was proposed as a means of using and expanding the aging urban and suburban rail network, a 5-year alternatives analysis was conducted during which three options were compared: (a) closure of rail network and shift of emphasis to buses, (b) retention of network as commuter rail, and (c) conversion of network to LRT.

This process began with the assumption that no project was feasible that did not use the existing less expensive right of way. Ninety percent of the right of way ultimately used already existed. Although this was a strong effort, it should be noted that even here no route corridors or land use schemes appropriate for completely different applications were considered. Other cities in Britain, however, have conducted wider strategic studies before developing specific transportation schemes for implementation.

In the United States, new LRT and other urban rail systems are almost always built with financial assistance from the federal government. Applicants for federal capital contributions had to compare new LRT project proposals to alternatives that include transportation system management, defined as low-capital investments and strategies to improve use of existing facilities, and a no-build option, which continues the present investment level. Since 1980 transit agencies have been required to produce environmental impact statements for new projects. The federal government does not require comparisons to be based on a benefit-cost analysis. The initial phase of the San Diego Trolley was built with state and local funds, eliminating the federal alternatives analysis requirement. Metro and bus system improvements were discussed as alternatives to LRT, but analysis of alternatives appears to have been limited. The Intermodal Surface Transportation Act of 1991 requires analysis of the social and environmental costs and benefits of all major metropolitan transportation investments, including transit, highway, and other alternatives (*3*).

France undertook alternatives analyses before construction of LRT systems, but decision rules and the depth of evaluation are not clear. Expanded and improved bus systems appear to have been rejected because they were not able to meet needs cost-effectively using existing technology. Nantes and Grenoble sought to increase capacity, lower operating costs, reduce congestion and air pollution, and use existing rights of way. In Nantes, the assessed alternatives included shared use of existing rails, a trolleybus system, and a metro. In Grenoble the options besides LRT were a cable car system and a metro. Noncapacity changes to improve the management or pricing of existing facilities were not discussed. However, the LRT system in Grenoble costs less to operate and carries more riders than did the exclusive bus system. French grant incentives favoring dedicated right of way and infrastructure work may have encouraged the decision to build LRT.

When considering its Nieuwegein LRT, the Netherlands rejected metro as too expensive. A high-speed bus system was also considered, but was rejected despite a lower cost. According to a Dutch transportation official, it "was doubtful whether a fast bus system will generate the same ridership" because marketing studies indicated that passengers might not regard buses as favorably as LRT. It should be noted, however, that the Dutch decision-making process uses other factors in addition to cost and the effects of willingness to pay, with a stated policy "to provide fast and reliable services which are sufficiently attractive to divert trips by car to public transit, particularly in congested corridors."

The Hannover tram system was gradually upgraded to LRT standards, and new extensions were built without detailed analysis of alternatives. A metro was rejected because of high costs; busways and transportation system management were not seriously considered.

In general, alternatives analysis could be more thorough, with consideration of a broader range of options and market studies. Route designations could focus more on travel demands than on specific technologies. When planners are urged to define benefits narrowly (users only), they can underestimate the value of projects. The existing costs of subsidies to automobile users, through underpriced road use, are rarely added to the comparisons. These opposing pressures might balance one another, but they can distort assessments. To encourage informed, rational decisions, benefits and costs should be properly assessed and publicly provided goods should be correctly priced. Alternatives analysis alone may not guarantee selection of an "optimal" investment, because transit planners often work with limited information and in politicized environments, but careful project evaluation adds rigor to all transportation investment decisions.

Pricing and Fare Recovery Policy

LRT systems encourage efficiency by striving to recover expenses through fares rather than public subsidies. Although ridership is expected to respond to reasonable fares and appropriate service levels, expectations vary. The British government has required that Manchester's LRT system recover 100 percent of its operating costs through fares, though it is not clear what will happen if this mandate is not achieved. The purpose of the requirement is to allocate costs fairly and encourage the local executive, which holds an interest in the 75 percent private operating consortium, to set efficient service levels that are based on user willingness to pay. Manchester also hopes to recover capital expenses not covered by the initial government grant through operating profits. San Diego also seeks 100 percent recovery, which is unusually high for the United States. In Switzerland most local transit systems are expected to achieve a recovery rate of 65 percent. No fare recovery goals are indicated for France, but the involvement of private equity could provide additional incentives for efficient performance. Germany and the Netherlands note no fare recovery goals; the Netherlands uses national fare collection and does not report cost recovery for each system.

Light Rail System Ownership and Operating Funding Policy

LRT lines are generally publicly controlled. Only the San Diego has facilities jointly owned by public and private entities. On the extension to the central city's Bayside neighborhood, the operator and private investors built and jointly own LRT stations in two new mixed-use real estate developments, sharing costs and risks.

To encourage efficient service, three of the systems studied involve private interests in LRT operation. Rolling stock and infrastructure in Nantes and Grenoble are owned by the local transportation organizing authorities; operation is entrusted to mixed-economy companies with 35 percent of equity held privately. In Manchester the right to operate and maintain the system and set fares was given to the same private consortium that designed and built the system, all through a single design-build-operate contract. This arrangement was intended to induce efficient construction and reasonable service levels. The San Diego Trolley is publicly operated, but a private security force is used and a freight railroad company rents the right of way during hours when LRT is not in service. The Dutch, Swiss, and German LRT systems are entirely public. In all the countries except Britain, operating deficits are covered by subsidies from federal, regional or state, and local governments. In Britain, shortfalls are made up by the operating government or through service changes.

Capital Funding Policy

Capital funding requirements affect how LRT systems are designed and determine whether or not they are built. LRT investment funds come from combinations of national, state, and local sources in France (30 percent national), Germany (60 percent national), the Netherlands (100 percent national), and Switzerland (50 percent national). National and local governments demonstrate need for a system together, costs are estimated, and grants and tax levies are legislated. France allows transit organizing authorities building public transit on dedicated right of way with national subsidies to raise local capital through a dedicated tax on wages of up to 1.75 percent. Both Nantes and Grenoble used this device. Manchester sought public savings by funding capital with national (50 percent) and local grants but contracting design and construction to a 75 percent private company, further encouraging efficiency and shifting some costs to the private sector. The British government required such private involvement as a condition of providing the public capital grant, precluding an entirely public project. Manchester also expects to recover a portion of capital costs through its future stream of operating revenues.

San Diego's capital funding process was unusual. Most U.S. transit systems have obtained 75 percent of their capital funds from the federal government. In contrast, construction of the first San Diego Trolley line was financed entirely by a combination of state gas and state and county sales taxes, which allowed LRT planners to avoid complex federal grant conditions relating to material sources, cost projections, contracting, and other design features. San Diego County adopted a $^1/_6$-cent transportation sales tax to fund LRT extensions. The transportation sales tax was approved by referendum and ensures that costs are borne, in part, by residents of its service area. San Diego County also contributes to an annual LRT depreciation fund, depending on fare box revenues, that reflects equipment costs and provides resources for future capital purchases.

Trade-Offs Between Financial and Nonfinancial Objectives

Although cost recovery through fares is an objective of all case study operators, the relative importance of this objective varies by country. None of the system descriptions suggests that profitability is the major goal of LRT service, although British LRT operators are expected to recover operating costs and minimize losses. Transit providers have a range of nonfinancial objectives, and governments have varying willingness to pay for them. Like ridership goals, these broad objectives can conflict with financial objectives such as fare box cost recovery.

Improved accessibility and mobility are also goals of all systems studied. In the United States, the Americans with Disabilities Act requires transit operators to make their systems accessible to those with disabilities. LRT systems in Britain, France, Germany, and the Netherlands are being made accessible through the use of equipment such as high station platforms and low-floor vehicles. The Manchester LRT uses profiled platforms and vehicles with doors at different levels, which together provide level access at a number of points. The Bern-RBS LRT has recently purchased 11 accessible two-car twin units and plans to buy more. All of these broader objectives must be balanced carefully with financial goals.

All operators seek to draw travelers out of their automobiles into public transit to promote environmental policies, including conserving energy and reducing toxic emissions from automobile use. In the United States, national ambient air quality standards require metropolitan areas that are not in compliance to make efforts to reduce air pollution emissions; transit development is one means of doing so. Under the Clean Air Act Amendments of 1990, U.S. cities with excessive ground-level ozone and carbon monoxide levels must reduce these pollutants by specified target dates or risk losing federal transportation grants (*4*). An explicit goal of the San Diego Trolley is to decrease emissions by encouraging drivers to switch to transit, reducing both automobile trips and congestion. For the European countries, the primary environmental goal related to transit is to reduce energy consumption and the resultant carbon dioxide production.

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Los Angeles Metro Blue Line Light Rail Safety Issues

LINDA MEADOW

Light rail transit systems have become popular because of their relatively low cost; ability to operate both on and off city streets, with intermediate capacity for transporting passengers; and frequent stops in urban areas. Most LRT systems operate portions of their systems in city streets, within median strips and in transit malls. Successful operation of LRT systems in the urban environment depends on integrated light rail and traffic signal controls. The operation of LRT systems in shared right of way presents a situation for accidents because of other users (motorists, pedestrians, bicyclists) in the right of way. Many safety problems are the result of motorists' and pedestrians' failure to obey or understand traffic controls. The Metro Blue Line (MBL) is a 22-mi LRT system that operates from downtown Los Angeles to the city of Long Beach. Approximately half of the MBL route runs parallel to an existing Southern Pacific railroad right of way, travels at speeds of up to 55 mph, and traverses 28 at-grade street crossings in areas of high traffic volume. The MBL Grade Crossing Safety Program was initiated in March 1993 to evaluate various ways to discourage or prevent illegal movements being made by vehicles at grade crossings that are causing train and automobile accidents. The safety program includes four elements: enforcement, engineering, legislation and bilingual public education.

Light rail transit (LRT) systems exist throughout North America in 18 cities in the United States and Canada. LRT systems have become popular because of their relatively low costs and ability to operate both on and off city streets, with intermediate capacity for transporting passengers, and frequent stops in urban areas. Many LRT systems operate portions of their systems in city streets in mixed traffic, within median strips, and in transit malls. Most systems have some grade crossings.

Design, construction, and operation of LRT systems requires a partnership between the transit agency, contractors, and the city and county traffic officials. Successful operation of LRT systems in the urban environment depends on integrated light rail and traffic signal controls. In addition, light rail crossings must be engineered in accordance with established safety principles and guidelines. The California Public Utilities Commission (CPUC) regulates light rail safety in California through a series of general orders. Some other states have state oversight agencies with similar safety requirements.

FTA has issued a notice of proposed rulemaking that will require all states to have safety oversight agencies for rail fixed guideway systems (*1*).

Operation of LRT systems in shared right of way (interaction with motorists, pedestrians, bicyclists) presents a situation for accidents and congestion. Collisions involving light rail vehicles and other users of shared right of way can result in significant safety problems. Many safety problems are the result of motorists' and pedestrians' failure to obey or understand warning devices and traffic controls.

Grade separation, where the LRT system operates above ground in a depressed guideway or subway, is the safest form of light rail operation. However, since grade separations are very costly to build, many properties do not choose this option.

LRT SAFETY ISSUES

Transit officials throughout the United States and Canada are working to develop effective treatments to reduce the number of collisions involving LRT trains. ITE recently conducted a survey of 17 LRT operating properties. Survey responses indicated a wide range of safety problems and areas of concern related to LRT operations in city streets and on reserved rights of way with at-grade crossings. The ITE survey identified the following:

- Motorist disobedience of traffic laws;
- Crossing equipment breakage and malfunction;
- Traffic queues blocking crossings;
- Vehicles exiting driveways stopping on tracks;
- Vehicles turning from streets running parallel to the tracks;
- Motorists running around closed crossing gates;
- Vehicles making left or U-turns in front of trains or stopping on tracks;
- Pedestrian conflicts at station areas and crossings;
- Light rail vehicles (LRVs) blocking street and pedestrian crosswalk areas at crossings;
- Motorist confusion over traffic signals, LRT signals, and signage at intersections; and
- Unusual crossing configurations.

The Transit Cooperative Research Program (TCRP), established under FTA sponsorship in 1992, includes FTA, the National Academy of Sciences, and the Transit Development Corporation. TCRP is sponsoring a 2-year program to improve the safety of LRT operations in shared right of way. The contractor selected for the program will investigate the effectiveness of passive and active signage currently in use at LRT properties; traffic signalization, including LRT indications; pavement markings; geometric improvements, including channelization and medians; audible warning devices, including bells, whistles, and horns; crossing illumination levels; illumination and marking of LRVs; moveable traffic barriers; applications of advanced technology; enforcement; and public education.

LRT GUIDELINES

Uniformly accepted standards for light rail signals, signs, and pavement markings do not exist anywhere in the world. The Cal-

Los Angeles County Metropolitan Transit Authority, 818 West Seventh Street, Suite 1100, Los Angeles, Calif. 90017.

ifornia Traffic Control Devices Committee Light Rail Safety Subcommittee recognized the need for uniformity of signs, signals, and markings on roadways and LRT alignments in California. This committee has prepared a draft *Light Rail Safety Manual,* which contains guidelines for light rail signals, signs, symbols, markings, and other information related to the planning, design, and operation of light rail systems. When adopted by the California transit operators in final form, the *Light Rail Safety Manual* will be a primary reference for the design, development and operation of LRT systems.

Part 8 of the *Manual on Uniform Traffic Control Devices* addresses traffic control for railroad-highway grade crossings in the United States (*2*). However, the LRV interaction with motorists, pedestrians and bicyclists with LRT equipment differs from their interaction with traditional railroads because of the high speeds, frequency of service, and other factors. A draft Section 8E on LRT in the United States has been prepared by the Light Rail Task Force of the Railroad-Highway Grade Crossing Technical Committee of the National Committee on Uniform Traffic Control Devices.

METRO BLUE LINE HISTORY

The Los Angeles County Metropolitan Transportation Authority (MTA) is planning over 400 mi of light, heavy, and commuter rail over the next 30 years. Operational lines include the Metro Blue Line (MBL), a light rail line; the MRL, a heavy rail line; and Metrolink, a network of commuter rail lines serving five counties. The Metro Green Line, now under construction, is scheduled to open in 1995.

MBL Overview

The MBL is an LRT system that operates through three cities and unincorporated areas of Los Angeles County, running south from downtown Los Angeles to the city of Long Beach. After 3 years of operation, ridership averages approximately 42,600 passengers a day (Figure 1).

The total route is approximately 22 mi long, with 12 mi of the route (cab signal segment) following an existing Southern Pacific railroad right of way that runs through south-central Los Angeles and Compton. Freight trains use the Southern Pacific tracks that run adjacent to the MBL tracks. Vehicles and pedestrians using at-grade street crossings in this area must cross two MBL tracks as well as one or two Southern Pacific tracks.

On the cab signal route segment MBL trains run under automatic train protection. Train operations are controlled by operators, and speeds are governed by cab and wayside signals. Over this route segment MBL trains travel at speeds up to 55 mph and traverse 28 at-grade street crossings. Many of the grade crossings are located at major streets carrying high traffic volumes. In addition, busy streets run parallel to the tracks at 26 of the 28 grade crossings.

Over street running route segments in downtown Los Angeles and downtown Long Beach (approximately 10 mi), trains are operated according to train T-signals, traffic conditions, and traffic signals. CPUC regulations limit speeds on these route segments to 35 mph. Partial priority is being implemented for certain street running segments.

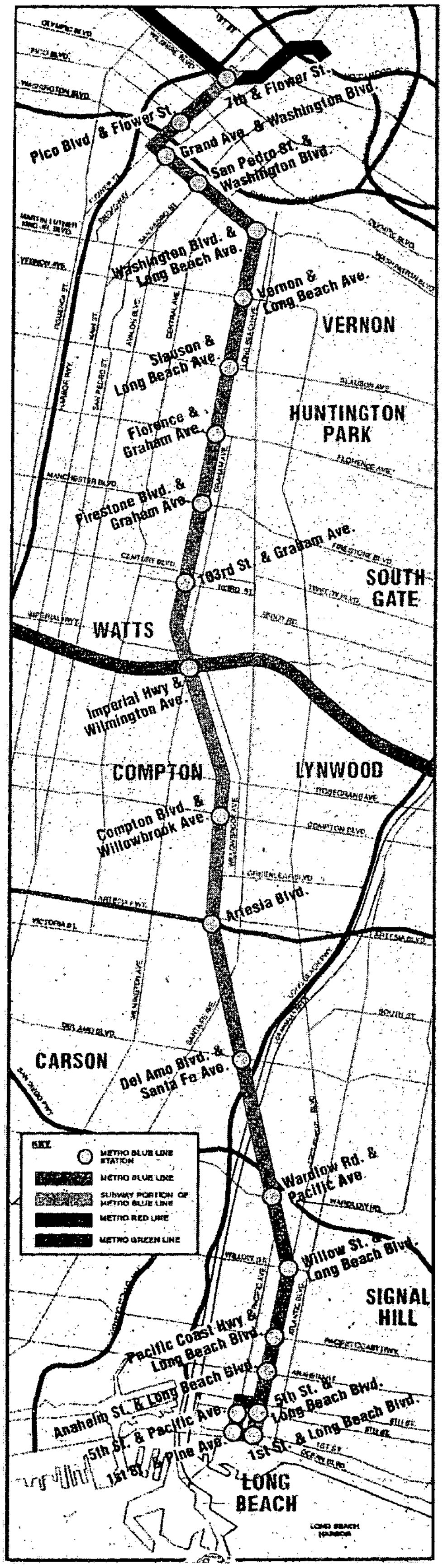


FIGURE 1 MBL map.

Overall, there are 100 grade crossings on the MBL. All of the crossings are protected using appropriate signs and equipment. Crossing protection devices include traffic signals, gates, flashing lights and bells, and stop signs.

MBL Accident Experience

In the 3 years from the opening of the MBL through the end of June 1993, there have been 158 train vehicle and 24 train-pedestrian collisions resulting in 16 fatalities and many injuries. In the MBL's mid-corridor section, motorists have been hit by trains after driving around closed crossing gates against flashing lights and bells. The trains have been moving at high speeds and the accidents have resulted in fatalities and serious injuries. Nearly all of the accidents in street running have been caused by vehicles making illegal left turns because they ignore or do not see red No Left Turn arrows.

Most MBL grade crossings where trains run at high speeds are complicated by several factors that greatly increase the potential for collisions.

Motorists Driving Around Gates

Streets running parallel to the tracks make it possible for motorists making left turns from the parallel streets to drive around lowered crossing gates. A crossing three or four tracks wide makes it easier for motorists to drive around lowered gates in an S pattern.

Multiple Train Tracks

Slower-moving Southern Pacific freight trains run on tracks adjacent to the MBL tracks. Motorists seeing a freight train approaching that is still some distance away might drive around lowered crossing gates without realizing that the gates were activated for an approaching MBL train. More than half of the train-vehicle collisions at crossings on the MBL's cab signal route segment have occurred when a second train, either an MBL or Southern Pacific, has been passing through the crossing.

Frequency of Trains

Trains running as frequently as every 6 min in each direction make it more likely that the gate down times will be extended to allow trains to pass in opposite directions. Soon, the frequency of MBL trains may be increased to as often as every 4 min in order to handle the line's standing-room-only loads in peak periods.

OVERVIEW OF MBL GRADE CROSSING SAFETY PROGRAM

The Los Angeles MBL Grade Crossing Safety Program was initiated in March 1993 to evaluate various means to discourage or prevent illegal movements being made by vehicles at grade crossings that are causing train-automobile accidents. Although the program is focused primarily on evaluating measures to decrease train-automobile accidents, the safety program is also concerned with improvements that will reduce train-pedestrian accidents. MTA is seeking to apply innovative equipment and methods developed for street and highway traffic applications. These engineering improvements will address the unique characteristics of MBL grade crossings and improve public safety.

The safety program includes four elements:

- Enforcement using sheriff's deputies and photo enforcement systems;
- Engineering improvements including use of intelligent vehicle-highway system (IVHS) technologies, warning devices, and street and traffic signal improvements;
- Legislation to establish higher fines and statewide rail safety educational programs; and
- Bilingual public information and safety education.

ENFORCEMENT

Grade crossing enforcement programs include the Los Angeles County Sheriff's Department (LACoSD) Transit Services Bureau traffic detail and photo enforcement systems. MTA contracts with the LACoSD to provide police services for the MBL and to be highly visible on station platforms and trains. This high-level security has served to discourage criminal activity on the trains, at the station areas, and in parking lots.

LACoSD Transit Services Bureau Grade Crossing Traffic Enforcement Program

Starting in June 1992 for a 90-day demonstration period, the Sheriff's Transit Services Bureau established a traffic detail to provide increased enforcement of traffic violations at selected grade crossings. Ten traffic detail deputies were deployed on two shifts a day, 7 days a week, for nearly 13 weeks. The traffic deputies wrote 7,760 citations in 90 days. Because of the success of the program, continuing funding for six deputies was authorized. These deputies have issued more than 11,000 citations in the first year of this effort.

Deputies obtained information from violators on a short survey questionnaire for the first 1,500 violators. The responses indicated that 63 percent of the violators were frequent users of the grade crossing and that 40 percent thought it was safe.

Photo Enforcement Demonstration Program

MTA is conducting a demonstration project involving the installation of photo enforcement systems at four grade crossings along the MBL. Photo enforcement systems involve the use of high-resolution cameras to photograph violators and provide one or more photographs of the vehicle, its license plate, and the driver's face as the basis for issuing a citation. Superimposed onto each photograph is the date, time, and location of the violation as well as the speed of the violating vehicle and number of seconds of elapsed time since the red flashing lights were activated. At crossings with traffic signals, the number of seconds of amber and red signal time are shown.

Photo enforcement technologies have been used—worldwide including in the United States, Europe, and Canada—to capture speed and red light violations. The use of photo enforcement for speed and red light violations has significantly reduced accident rates wherever it has been used.

The U.S. Department of Transportation is funding an evaluation of the effectiveness of photo enforcement at MBL grade crossings. Funding participants include FRA, FHWA, and FTA.

Photo Enforcement Installation in Cab Signal Territory

The photo enforcement cameras are mounted in a bulletproof box on top of an 8–ft pole. A bilingual (English and Spanish) sign tells motorists that photo citations are issued to violators (Figure 2). The camera, located on the southeast corner of the intersection, views the eastbound traffic lanes, monitoring through traffic and left turns from the parallel roadway. Inductive loop detectors buried in a shallow cutout in the road are used to detect the presence of a vehicle when the gate arms begin their descent.

When the violator's automobile crosses the detection loops while the grade crossing signals (gate arms) are in operation, a photograph is taken with data superimposed. Then, approximately 1.2 sec later, another photo is taken that shows the violating vehicle traversing the intersection (Figure 3).

The vendor develops the film, views each photo to see the license plate and image of the driver, and then runs a Department of Motor Vehicles (DMV) check to determine the registered owner of the vehicle. A citation is printed in both English and Spanish and is sent to the registered owner. Citations are issued within 72 hr of the violation.

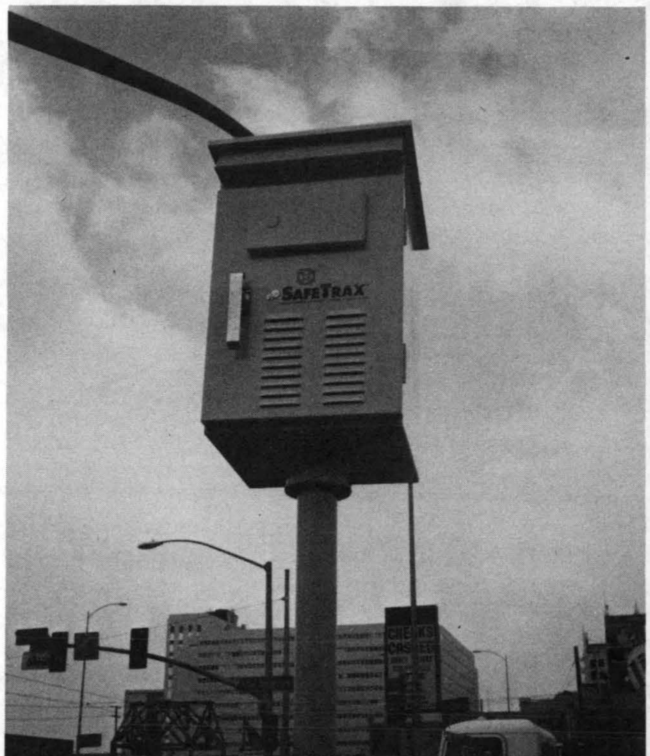
Photo Enforcement in Street Running Territory

In the street running segments, the camera photographs violators making left turns against a red left turn arrow. Street running territory has traffic signals and light rail signals but no rail crossing gates. At the intersection of Los Angeles Street and Washington Boulevard in the city of Los Angeles, inductive loop detectors have been cut into the street to detect automobiles making left turns against a red left arrow indication.

A different approach, using IVHS technology, is being demonstrated in Long Beach, at Willow Street and Long Beach Boulevard. Vehicle detection is being accomplished with video image processing using Autoscope, which includes imaging hardware (video camera), a processor, and software (as seen in Figure 4).

The Autoscope system can detect traffic in many locations within the field of view of the camera. The user specifies the

FIGURE 2 Photo enforcement sign and pole.



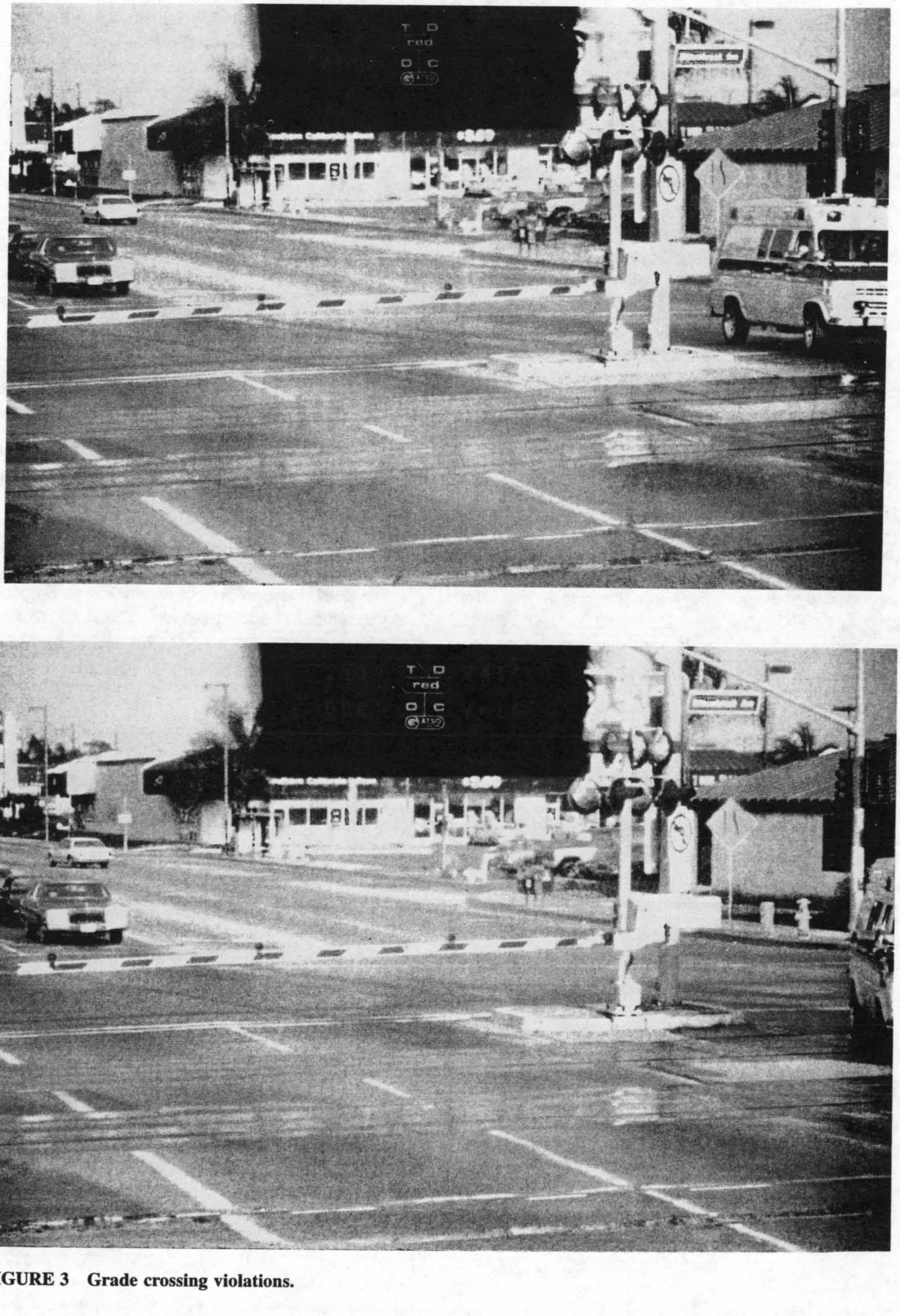


FIGURE 3 Grade crossing violations.

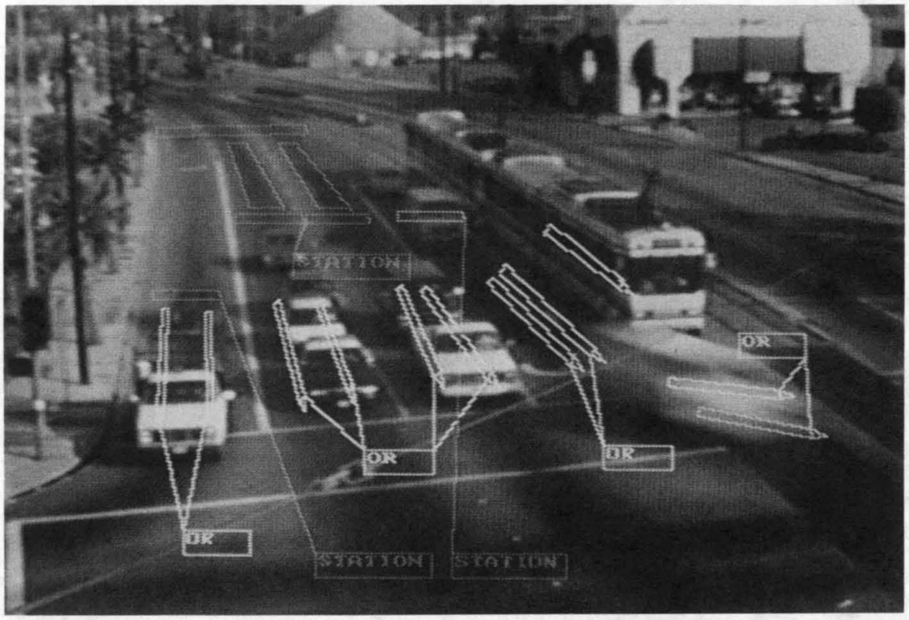


FIGURE 4 Autoscope screen at Long Beach Boulevard and Willow.

locations using interactive graphics. Detection lines are placed along the rail or street on a television monitor that displays the traffic scene. Whenever an automobile or train crosses the detection lines, a detection signal is generated by the device.

Figure 4 presents an image of Long Beach Boulevard as seen by Autoscope. The detector overlay show the vehicle detectors used; those shown in blue (on original screen) have detected a vehicle. The detector on the train is the train detector, and the two across the train track detect a crossing car, as would be desired in a safety application. Detectors can be moved to any location desired in the image, and those shown in brown on the original screen have not detected a vehicle but could do so.

The Harvey Mudd Engineering College is testing the use of a lower resolution digital camera for photo enforcement. Photographs will be transmitted from the camera location to a central processing unit, which eliminates the need for changing film and offline film development.

Results

The photo enforcement program has been extremely successful in terms of reducing numbers of motorists who are violating grade crossings.

Cab Signal Territory The Compton photo enforcement demonstration program was started on November 19, 1992. For the first 2 months, the camera equipment was operated at two crossings in the city of Compton (Alondra and Compton Boulevards, approximately 0.5 mi apart) where poles were installed without any press coverage, public announcements, or signs. During this period, counts were made of the number of violations to serve as a baseline for evaluating the effectiveness of the equipment.

On January 19, 1993, a press conference was held to announce the use of the equipment at the two crossings. Warnings were sent to motorists violating the crossing signals and gate arms when trains were approaching. Signs were installed at the crossing on February 11, 1993. On March 19, 1993, violators were issued citations. The 4-month photo enforcement demonstration project at Compton Boulevard was completed July 19, 1993.

The demonstration project resulted in an 84 percent reduction in the number of violations occurring at the crossing, ending up at 0.15 violations per hour for the last 2 months of the project (Figure 5). Citations were processed by the Compton Municipal Court. During the 4 months of the demonstration project, 548 violations were recorded by the camera equipment at the crossing; 232 citations were issued to violators.

The camera equipment was reinstalled at Compton Boulevard on September 9, 1993, and left there through the end the month to determine if the violation rate had declined further. With a visible sign and camera box, but no citations issued, the violation

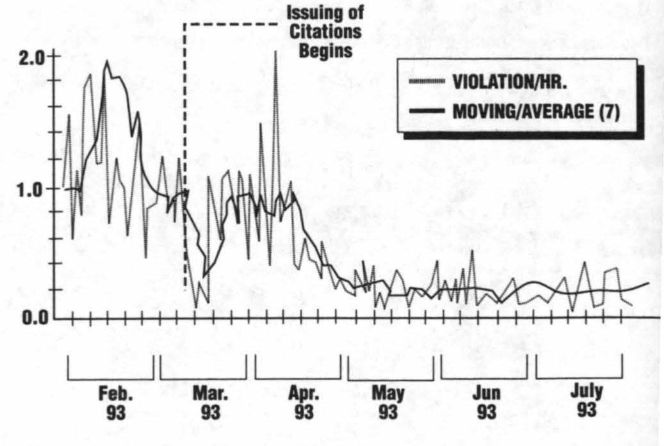


FIGURE 5 Hourly grade crossing violation.

rate declined to one violation every 12 hr (or 0.07 violations per hour).

A 3-month demonstration project was completed at Alondra Boulevard on September 9, 1993. Signs, a camera pole, and cabinet were installed for about 6 months at this location before citations being issued. Grade crossing violations dropped from 0.5 violations per hour in December 1992 to 0.16 per hour in September 1993 when the demonstration project was completed. The rate of violations had declined to approximately 0.28 violations per hour when citations were first issued in June 1993, indicating that a portion of the reduction in grade crossing violations could be attributed to the signs, installation of the pole and cabinet, and enforcement efforts at Compton Boulevard. During the 3 months of the demonstration project, 254 violations were recorded by the camera equipment at the crossing, and 142 citations were issued to violators. The lower number of citations is due to vehicles with no front plate, out of frame, windshield glare, or other factors where the driver is not clearly identifiable.

Twenty percent of the citations issued (79) resulted in calls to the vendor to view the photo. Out of these calls, 26 percent of the motorists who called to make an appointment did not appear. Initial figures on the rate of payment of citations show the payment rate to be approximately the same (50 half) as for citations issued by the Los Angeles Sheriff's Department Traffic Detail.

Because of the success of the photo enforcement demonstration projects, MTA is currently proposing to install cameras at 17 additional grade crossings on the MBL.

Street Running Territory The intersection of Los Angeles Street and Washington Boulevard has a very high number of left turn violations. At this intersection, the camera equipment has been installed to capture left turns made against a red left turn arrow from eastbound Washington Boulevard to northbound Los Angeles Street (toward downtown Los Angeles). The camera has a 150-mm lens which provides photographs showing a closer view of the driver's face and vehicle license plate. Issuance of warning notices began on October 27, 1993. Citations will be issued in mid-January 1994. There was an average of 2.0 violations per hour on weekdays before sign installation. After installation of the signs and mailing of warning notices, the rate of violations has dropped to 1.5 per hour.

ENGINEERING

The MBL was designed and constructed in accordance with industry safety guidelines and standards. Examples include sophisticated train control systems, active warning devices at grade crossings, signage (both regulatory and warning), light rail signals, and pavement markings. However, operating experience has shown the need for additional engineering improvements such as street and traffic signal system improvements, demonstration of four-quadrant crossing gates, demonstration of pedestrian gates, and the testing of a train operator actuated wayside horn system.

Street and Traffic Signal Improvements

Street and traffic signal system improvements include the following projects.

Left Turn Lanes and Signal Phasing

Los Angeles is installing separate left turn lanes, signal phases, and red left turn arrows at five crossings where Long Beach Avenue runs parallel with the MBL and Southern Pacific tracks. These improvements are being installed running southbound only on the west side of the tracks and northbound only on the east side of the tracks. Separate left turn lanes will provide motorists with a place to wait when making left turns across the tracks.

Medians

Raised medians or center line curbs are very effective in restricting motorists from driving around lowered crossing gates. Several grade crossings on the cab signal route segment have raised medians on one or both approaches to the crossing. However, streets running parallel to the tracks or other geometric design features do not allow the construction of medians on one or both approaches. As part of this program, raised concrete medians, centerline curbs, or plastic delineators are being constructed on one or both approaches at seven MBL grade crossings where medians can be placed without disrupting traffic on streets running parallel to the tracks.

Programmed Visibility Heads

At 16 intersections on Long Beach Boulevard where MBL trains are street running, the overhead traffic signal heads for left turns and through traffic are close together and can be confusing for motorists making left turns. At these locations, the through and left turn signal heads will be replaced with programmed visibility heads so that motorists turning left will be able to view the left turn signal but not the through signal.

Illuminated Train Coming Signs

Improved signage to warn drivers that trains are approaching may be effective in reducing the number of train-vehicle collisions, especially on street running route segments or at grade crossings at which left turns across the tracks are possible and no traffic signals are installed.

Illuminated yellow train symbols or Train Coming or Train (Figure 6) signs will be installed at two grade crossings, on Washington Boulevard in Los Angeles. A focus group will be conducted to determine which sign conveys the message that a train is present.

Four-Quadrant Crossing Gates

There are diverse opinions concerning the use of four-quadrant gates at grade crossings. Many rail professionals are concerned that the gates may trap motorists on the tracks and, if the gates fail in a lowered position, block emergency vehicles from passing and create unacceptable traffic jams. Conversely, there are at least three design-related factors typical of many MBL grade crossings that make it appropriate to consider the use of four-quadrant gates. Several grade crossings require vehicles to cross three or four

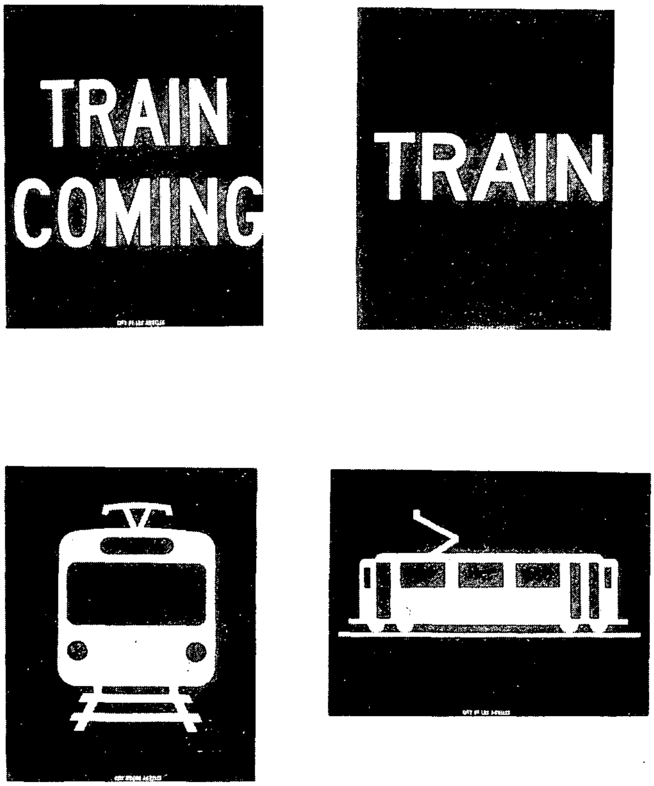


FIGURE 6 Illuminated train warning signs.

tracks. The width of these crossings makes it easier for vehicles to drive around lowered crossing gates, making an S movement.

In addition, vehicles are able to make left turns from streets running parallel to the tracks at many MBL grade crossings. Drivers can turn easily around lowered crossing gates when trying to avoid being delayed by a train.

Many of the accidents on the cab signal route segment have involved a vehicle driving around lowered gates to avoid waiting for a slow-moving freight train or after a train passes through the crossing. The vehicle is then hit by another train that was not seen by the driver. Typically in this situation, the crossing gates are down for a longer time than usual (or the driver, seeing a slow freight train approaching, anticipates that the gates will be down for a longer time).

Demonstration Project Objectives

A highway-rail grade crossing may be considered to have four quadrants, formed by the rail tracks (running from left to right) and the street or highway crossing the tracks (running from top to bottom). With a four-quadrant gate system, a crossing is completely closed off when trains are approaching by gates on both entrances (the typical crossing gate configuration) and by gates on both exits from the crossing.

The use of this type of crossing gate system offers an approach for eliminating or minimizing grade crossing accidents without the high costs and impacts of grade separating. For the MBL, it offers the potential for eliminating collisions involving motorists turning left from streets running parallel to the tracks. Additionally, this system can potentially decrease the number of collisions involving motorists driving around closed crossing gates from the crossing street.

The objectives of the demonstration project are to

- Design and install a four-quadrant gate system which eliminates the risk of motorists being trapped between closed entrance and exit crossing gates;
- Investigate the use of new technologies, collectively referred to as IVHS and becoming more widely used for a variety of street and highway traffic improvement applications, for improving highway-railroad grade crossing safety;
- Evaluate the effectiveness of a four-quadrant gate system in preventing accidents caused by drivers going around closed crossing gates in an urban area LRT operating environment; and
- Determine the additional costs of constructing and maintaining a four-quadrant gate system.

Existing North American Four-Quadrant Gate Installations

Four-quadrant gate systems are currently operational in the United States and Canada at three locations:

- Broad Street in Red Bank, New Jersey, as part of New Jersey Transit;
- 24th Street in Cheyenne, Wyoming, as part of the Burlington Northern; and
- 20th Avenue in Calgary, Alberta, as part of Calgary Transit.

Planned installations include

- Gillette, Wyoming, on the Burlington Northern;
- Charlotte, North Carolina, on the Norfolk Southern; and
- The proposed high speed rail corridors that are part of the Section 1010 of the Intermodal Surface Transportation Efficiency Act of 1991. For example, the Florida Department of Transportation has identified 7 out of 73 crossings on the 67-mi Miami–to–West Palm Beach corridor for the installation of four-quadrant gates.

Design Approach and Assumptions

Three safety features, involving different approaches for preventing vehicles from being trapped between the lowered entrance and exit gates, have been considered as elements of the basis for design for the four-quadrant crossing gate system. They are as follows:

- *Delay in lowering exit gates.* The exit gates will be lowered a number of seconds after the entrance gates are down (or have started down). The exit gates at the Broad Street, New Jersey, crossing where four-quadrant gates are used are delayed by 8 to 10 sec after the entrance gates are lowered. At the 24th Street crossing in Cheyenne, the exit gates are delayed by 2 to 4 sec after the entrance gates are lowered. In proposed guidelines issued in November 1992, FRA suggested that exit gates start down from

1 to 3 sec after the entrance gates start down, providing only a short delay time in the lowering of the exit gates.

- *Vehicle detection system.* The exit gates will not be lowered if a vehicle is detected in the track area. A vehicle detection system, using inductive loops to detect the presence of vehicles, will be interfaced with the exit gate control circuits so that the exit gates are not lowered when a vehicle is detected in the track area (Figure 7). Four-quadrant gates installed at crossings on the Swedish National Railway System are reported to use inductive loop vehicle detectors in this manner.
- *Exit gates fail-safe in "up" position.* The exit gates will be counterbalanced so that they are fail-safe in the "up" position. The gates will need to be driven down and then held down using a "holder clear" type device or other means.

MTA will proceed with a four-quadrant gate demonstration at one crossing on the MBL.

Pedestrian Gates

In the first 3 years of the MBL operations, there have been 25 reported accidents involving MBL trains and pedestrians. Nineteen of the 25 accidents occurred in the cab signal section where the MBL and Southern Pacific share operations, and the LRV operates at speeds up to 55 mph. Most of the accidents occurred at station locations, but most of the fatalities occurred at grade crossings not adjacent to stations. In most locations pedestrians crossings are controlled by flashing lights and bells.

Many of the train-pedestrian accidents appeared to involve pedestrian inattention. In all cases the warning devices (flashers, gates, bells) at the accident locations were operational at the time of the accidents. Whether pedestrians heard or saw the warning devices is not known; however, some of the accidents involved pedestrians in a hurry to catch a train or bus and the pedestrian trying to beat the train.

A recently completed MBL Pedestrian Safety Study provided several general recommendations for treating pedestrian light rail safety issues.

- A barrier should be installed at the end of all walkways leading to/from platforms to delineate the crosswalk edge from vehicle lanes; raised plastic delineation should be installed at the ends of all medians or curbs that are adjacent to MBL tracks.
- Left turn vehicle tracking should be installed at intersection locations to delineate the vehicle left turn path so pedestrians avoid this area.
- All pedestrian crossings of light rail tracks should have primary warning signs installed.
- The crosswalk edge that separates the vehicle lanes from the crosswalks should have curbing installed, between track areas, along the entire length of the track crossings where vehicles are not allowed.

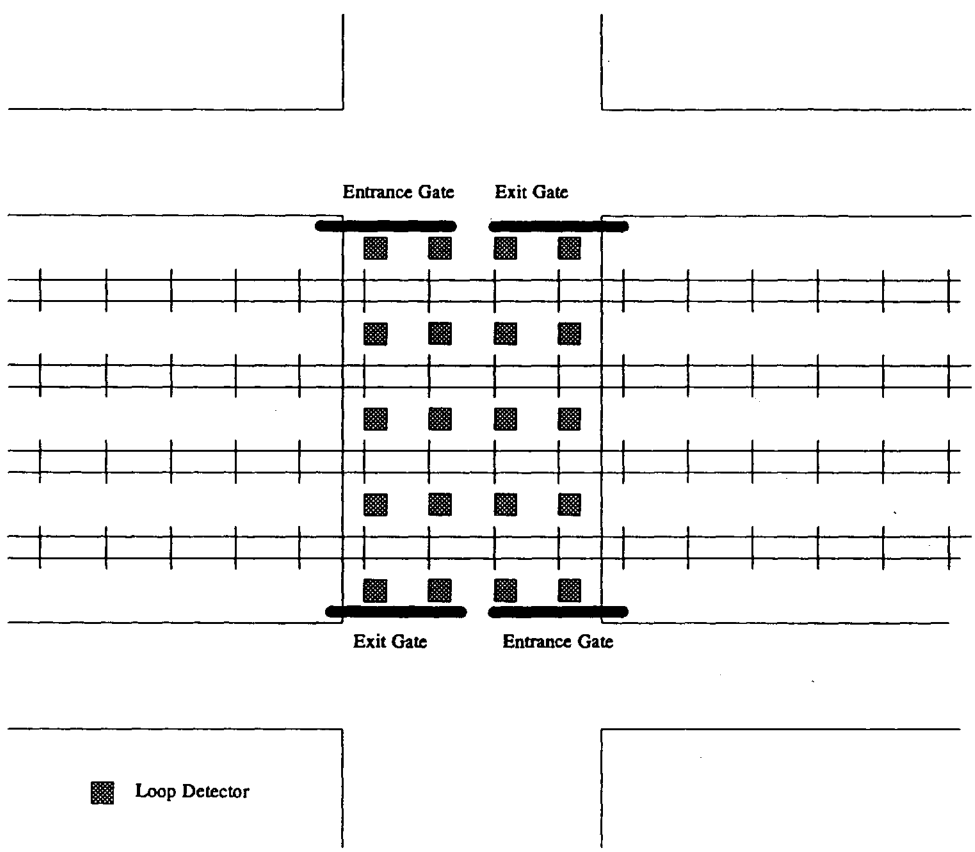


FIGURE 7 Installation of loop detectors at crossing equipped with four-quadrant crossing gates.

- Traffic signal sequences at those locations controlled by crossing gates should be standard along entire line.
- Pedestrian crosswalks crossing tracks in all locations should have standard white crosswalk lines.
- All pedestrian crossing surfaces should be different from street surfaces.

Part of the MBL Safety Program involves the demonstration of pedestrian gates at stations and at one or more pedestrian crossing areas. Three types of barriers are under consideration: railroad-style pedestrian gate areas, Calgary swing gates, and Z-gate channeling.

Criteria used to select pedestrian barrier demonstration installations include

- Number of pedestrian accidents,
- Accident types that can be mitigated with pedestrian barriers,
- Physical characteristics of crossing areas,
- Pedestrian inattention,
- Train speed,
- Second train approaching, and
- Level of pedestrian activity.

Train Operator–Actuated Wayside Horn System

MBL train operators are required to sound the train horn when approaching grade crossings. For grade crossings on the cab signal route segment, the horns are sounded 6 to 8 sec before trains enter the crossings.

In accordance with CPUC General Order 143-A, train horns are required to provide an audible warning of at least 85 dBA at a distance of 100 ft from the train. Although intended to warn motorists and pedestrians at grade crossings, the train horns can be loud and disruptive for persons living and working adjacent to the MBL tracks. For the MBL as well as other rail projects in Southern California, wayside horns may provide an effective means of mitigating certain noise impacts resulting from train operations.

An MBL wayside horn demonstration project is under way. The train horn will be mounted on a pole at two adjacent crossings. When the operator actuates the horn by pushing the button in the train cab, the horn will sound at the crossing. Microwave technology is being used to transmit and receive appropriate radio frequencies. If the wayside horn fails and is not operational, the on-train horn will sound. In addition, the train operator will be able to actuate the on-train horn for trespassers as needed. Noise measurements and community surveys will be made to evaluate the effectiveness of the wayside horn project.

LEGISLATION

MTA successfully sponsored the Rail Transit Safety Act, which seeks to decrease the number of rail-related accidents by imposing additional fines and points on persons who violate rail grade crossing safety laws. The act gives county transportation authorities, local governments, and law enforcement agencies the tools needed to implement expanded enforcement and public education efforts targeted at rail grade crossing safety.

Specifically, the Rail Transit Safety Act provides for the following.

- *Additional fine for grade crossing violations.* Currently, depending on the jurisdiction, the fine for not stopping at a grade crossing when the warning signals are flashing or for driving around a closed gate is $104, whereas the fine for a high-occupancy vehicle lane violation, where the violation does not threaten the life of the driver or of others, is $271. The Rail Transit Safety Act authorizes the court to levy an additional $100 fine for a first violation of a rail grade crossing safety law. If a person is convicted of a second or subsequent offense, the court may order an additional fine of $200.
- *Traffic school for grade crossing violations.* A person convicted of a grade crossing violation may be ordered to attend traffic school and view a film on rail transit safety.
- *Section on crossing safety in DMV driver handbooks.* The act requires DMV to include language regarding rail transit safety. The DMV handbook has recently included information on rail transit. However, additional information on rail transit needs to be added.

EDUCATION

Public education is a critical part of a successful grade crossing safety program. MTA has an ongoing educational program for adults and children along the MBL.

About half of the MBL accidents and fatalities have involved persons with Hispanic surnames; therefore, several safety campaigns are being developed to address the Hispanic audience. MTA is developing a rail transit safety video in Spanish and English that will feature Spanish celebrity figures. In addition, MTA is participating in a Southern California Superman campaign that includes Southern California commuter and freight railroads as well as light and heavy rail transit systems. The theme of the campaign is "Superman is more powerful than a locomotive ... you're not!" The Superman campaign will involve 7 to 8 months of media exposure including television commercials, public service announcements, brochures, and print advertising.

Representative educational programs include

- Operation Lifesaver safety programs;
- School safety programs such as Travis the Owl;
- Public tours to expose the public to rail safety;
- Safety placemat game, promoting rail safety in local fast food restaurants;
- Community outreach programs;
- Handout of rail grade crossing pamphlets and handbills to motorists at MBL crossings;
- Handbills and posters placed in businesses along the MBL;
- Church safety bulletins placed in weekly church bulletins; and
- Ongoing meetings with businesses along the rail line.

CONCLUSIONS

The objective of the MBL Grade Crossing Safety Program is to evaluate various means to discourage or prevent illegal movements being made by vehicles and pedestrians at grade crossings. Methods being evaluated include enforcement, engineering improvements, education, and legislation. Many of the techniques are proving to be successful in achieving the safety program objective.

Enforcement by the LACoSD Traffic Services Detail has proven to be very instrumental in apprehending motorists and pedestrians who violate grade crossings. The 90-day enforcement program produced 7,760 citations. Continuing grade crossing enforcement, using a smaller number of deputies, produces approximately 800 citations per month.

The photo enforcement demonstration project in Compton at two gated crossings resulted in an 84 percent reduction in violations. Violations went from a violation every 1 hr to a violation every 12 hr. During the 7-month demonstration project, 364 citations were issued to motorists.

During this period of intense enforcement, the accident rate in the cab signal area (gated crossings) went from 7 to 2 per year.

Engineering improvements are under way to construct medians at gated crossings, to add protected left turn lanes and signal phasing for streets parallel to the tracks, and to demonstrate four-quadrant and pedestrian gates. These engineering improvements are aimed at eliminating S-turns around down crossing gates and pedestrian inattention near the tracks.

MTA successfully sponsored the Rail Transit Safety Act, a statewide bill that imposes additional fines and points on persons who violate rail grade crossing safety laws. The act also allows a judge to order a grade crossing violator to attend traffic school and view and film on rail transit safety. In addition, it requires the DMV to include more information on rail transit safety.

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Overview of Light Rail At-Grade Crossing Operations in Central Business District Environments

HANS W. KORVE AND MARYANNE M. JONES

Light rail transit (LRT) agencies from 15 cities in the United States and Canada were asked to summarize existing and future light rail at-grade crossing operations issues, existing interjurisdictional relationships, block length constraints, and planned strategies to address both future LRT demand and at-grade crossing operations in the central business district (CBD). The study found that critical negotiations and planning issues exist if LRT systems will be expanding significantly or are newly implemented. For these systems, good interjurisdictional relationships are important in order to resolve current and future at-grade crossing issues; political commitment to LRT helps this process. Block-length constraints drive efforts to reduce headways to meet future demand. Overall, growing systems have turned to headway reductions, plus new LRT lines and line extensions, to satisfy future demand. These are costly strategies and will push at-grade crossings to their capacity limits in many cities. Advocated is local consideration of LRT at-grade crossing upgrades in CBD environments that will increase system efficiency and safety, perhaps delaying or obviating some capital and operating cost increases. A federal funding initiative in partnership with states and local governments is proposed that will provide a monetary incentive for local LRT agencies and cities that implement state-of-the-art at-grade crossing improvements.

This paper is intended as an overview of current and future at-grade operations issues being addressed by light rail transit (LRT) agencies in 15 cities in the United States and Canada, where at least a portion of downtown service is provided at-grade. LRT agencies were asked about the nature of the intersection conflicts and whether they have been able to resolve these issues. LRT agencies were asked about future at-grade crossing issues and what strategies were planned to address these issues.

These responses provided background information on system characteristics that may contribute to both existing and future at-grade crossing constraints. The effects of increased service levels and LRT construction programs on future LRT at-grade crossings were evaluated. The authors conclude by proposing methods for agencies and cities to seriously consider LRT at-grade crossing strategies, discussing their capacity and safety enhancement potential at the most preliminary stages of LRT planning efforts.

METHODOLOGY

Telephone interviews were conducted with operations staff from LRT agencies in 15 cities in the United States and Canada.

The following 11 agencies were asked to summarize existing and future light rail at-grade crossing operations issues and existing and planned strategies:

Korve Engineering, Inc., 155 Grand Avenue, Suite 400, Oakland, Calif. 94612.

- Baltimore: Maryland Mass Transit Administration (Maryland MTA),
- Boston: Massachusetts Bay Transportation Authority (MBTA),
- Buffalo: Niagara Frontier Transit Metro System (NFT Metro),
- Calgary: Calgary Transit,
- Los Angeles: Metropolitan Transit Authority (MTA),
- Pittsburgh: Port Authority of Allegheny County (Port Authority Transit),
- Portland: Tri-County Metropolitan Transportation District (Tri-Met),
- Sacramento: Sacramento Regional Transit District (RT),
- St. Louis: Bi-State Development Agency (Metro Link),
- San Diego: San Diego Metropolitan Transit Development Board (MTDB), and
- San Jose: Santa Clara County Transportation Authority (SCCTA).

Four other agencies [with no existing central business district (CBD) at-grade crossings] were asked to summarize future LRT at-grade operations issues and planned strategies:

- Philadelphia: Southeastern Pennsylvania Transportation Authority (SEPTA),
- Edmonton: Edmonton Transit,
- Cleveland: Greater Cleveland Regional Transit Authority (RTA), and
- San Francisco: San Francisco Municipal Railway (Muni).

STUDY FINDINGS

Interjurisdictional Relationships

Interjurisdictional agreements between LRT agencies and cities regarding at-grade crossing maintenance, operations, and other issues were discussed with LRT agency staff. In locations with low traffic growth and stable LRT systems, contact with the city department of transportation is routine, centering on operations and maintenance issues. For those systems that are newly built or expanding, basic implementation and design issues are also being discussed.

Locations with Stable LRT Systems

Many LRT systems that operate at-grade in downtown are located in regions with relatively low growth, more established systems, and little or no plans for LRT system expansion. Agency staff in these locations generally worked with the city during initial traffic signal design. Generally the LRT agency built the system and entered an agreement with cities to maintain the traffic signals, signage, and so forth. The operations and maintenance agreements that came out of these initial discussions (whether formal or informal) are operating satisfactorily, according to LRT agency staff.

Six agencies in low-growth regions stated that their contact with the local city staff concerned maintenance and routine operations issues: Baltimore, Pittsburgh, St. Louis, Buffalo, Boston, and Calgary. Of these agencies, only Baltimore has a formal agreement with the city; all other agency-city arrangements were characterized by LRT agency staff as informal. Table 1 provides details on these agreements, which have generally proven adequate.

TABLE 1 Interjurisdictional Relationships

LRT System Location/Agency	Agency/City Agreement Type	At-grade Crossing Issues Covered
Baltimore (Maryland MTA)	Formal	Routine maintenance and signal operations facilitating LRT progression.
Boston (MBTA)	Informal	Routine maintenance and signal operations. Initial meetings on xing signal design were satisfactory.
Buffalo (NFT Metro)	Informal	Routine maintenance and signal operations. Formal agreement has been pending for 8 years; informal arrangement is working.
Calgary (Calgary Transit)	Informal (LRT agency is part of City of Calgary DOT)	Routine maintenance and signal operations. Initial interdepartmental staff work on xing signal design was satisfactory.
Los Angeles (MTA)	Formal (with Long Beach and Los Angeles DOT's)	Interjurisdictional contacts are very active. Still resolving basic issues of LRT priority and crossing safety. ATSAC signal operation at xings is part of agreement, but is not yet operational. City of Long Beach grants LRT priority at minor CBD crossings, but priority is not given at three major arterials. Consultation on future LRT plans is also ongoing.
Pittsburgh (Port Authority Transit)	Informal	Routine maintenance and operations; train length and frequency mutually determined by agency and city staff.
Portland (TRI-MET)	Formal	Maintenance and operations; particularly strong relationships with local cities result in swift resolution of issues due to regional commitment to operations and expansion of LRT system. Portland uses a short-term (one month) "demonstration project" strategy to convince cities that LRT signal priority is workable. Ongoing consultation on future LRT plans.
Sacramento (RT)	Informal	Routine requests for city work crews to maintain signals, signage, tree trimming, etc. Regular contact, "about every other week". Also work with Caltrans when required.
San Diego (MTDB)	Informal	Routine maintenance and operations; also signal modifications and other improvements "of a minor nature", and future planning issues. Meetings occur as needed, usually every 1-3 months. Initial meetings on signal design was satisfactory.
San Jose (SCCTA)	Informal	Routine maintenance and operations, future planning issues. Initial consultation regarding design of xing signal system was satisfactory.
St. Louis (Metro Link)	Informal	Routine maintenance and operations; recently resolved gate down-time issues.

Locations with New or Expanding LRT Systems

One of the significant survey findings was that systems in growing urban areas, with significant LRT extensions in the works, or systems in the initial years of revenue operation discuss many more basic and critical issues than the systems described in the previous section. Contacts between the city and LRT agency can be contentious, as participants are attempting to solve fundamental issues. Sacramento is an exception to this rule; though RT plans significant LRT system growth, agency staff currently characterize their contacts with the city of Sacramento as being of a routine nature, centered on maintenance and operations.

SCCTA worked closely with the city of San Jose to design the signal system for the at-grade crossings in the downtown transit mall and elsewhere. During this process, critical safety and operations issues were resolved; now contacts with city transportation staff are more informal and center on maintenance and operations. However, as future signal modifications need to be discussed at crossings in downtown, another critical round of negotiations with city transportation staff will occur.

San Diego MTDB staff also worked regularly with the city to design the traffic signal control system for LRT priority on the existing downtown line. However, there are concerns on the part of MTDB staff and city transportation staff that are still being discussed at meetings conducted on an as-needed basis, usually every 1 to 3 months. Significant at-grade crossing improvements, as well as those of a minor nature, are discussed. Future LRT expansion plans also require essential consultation with traffic engineering staff.

The Portland and Los Angeles cases provide an interesting contrast of the effectiveness of negotiations between LRT agencies and cities. What makes negotiations in Portland more effective than in Los Angeles is not only a matter of negotiating style. It appears that a regionwide political commitment to transit service and infrastructure is a critical factor in determining the ease with which the issues related to at-grade crossings are resolved.

Portland LRT agency staff indicated that their institutional relationships with local cities are very strong, with swift resolution of at-grade crossing issues, not only for current operations and maintenance but also for planned LRT extensions. The region has made a long-term commitment to transit and has abandoned any policy to increase highway capacity. This allows multijurisdictional agreements to take place more smoothly than might otherwise be the case because local jurisdictions are largely in agreement on regional rail transit goals.

Portland has also successfully overcome the objections of cities resistant to granting LRT priority by convincing local staff to accept very short term LRT traffic signal priority demonstrations at selected crossings. Such projects can last no more than a month. Usually after the priority system is in operation, the local jurisdiction observes no negative effects on intersection operations and approves a permanent LRT traffic signal priority system.

By contrast, Los Angeles MTA contacts with the city of Los Angeles and the city of Long Beach, where street running segments are located, have not yet achieved successful implementation of planned LRT signal priority; issues of crossing safety are also under review. The city of Los Angeles has been working actively with MTA. However, the Automated Traffic Surveillance and Control (ATSAC) system installed at Blue Line crossings is still only in testing by the city of Los Angeles and is not yet operational. The city of Long Beach has given priority to LRT trains at many minor downtown crossings, but priority is not given at three major arterial cross streets. Issues are currently being resolved by direct consultation between MTA and affected jurisdictions; similar work is being undertaken on planned LRT extensions.

Because cities and MTA staff do not necessarily share the same regional commitment to LRT over automobile traffic considerations, critical issues still remain. Portland enjoys this regional commitment to LRT. Even though this fundamental difference is much more important than any single negotiating technique, the Portland strategy of installing 1-month signal priority demonstration projects could be tried in Los Angeles and Long Beach to help overcome city objections.

Existing At-Grade Crossing Strategies

LRT agency staff were asked whether they implement signal preemption and priority for light rail trains at downtown at-grade crossings and, if so, how it is accomplished. In most cases LRT agencies were satisfied with their choice of signal technology and the degree of LRT priority at at-grade crossings. Agencies tend to advocate their chosen technology as more cost-effective than others. Table 2 presents an outline of at-grade crossing strategies employed by each LRT agency.

Some cities that grant train priority have chosen to use a vehicle identification system that uses vehicle tagging known as VETAG, developed in the Netherlands. VETAG is best described as a system for the selective detection, identification, and location of vehicles. Other LRT systems have instituted or are trying to institute an ATSAC or similar type of traffic signal control system. Such systems control at-grade crossings using a computerized central traffic signal control system.

Buffalo and Portland use VETAG systems. These systems operate with standard signal controllers. LRT operators transmit a signal to the downstream signal controller when the train is ready to leave the station. The controller adjusts green and red times for opposing traffic and the train to allow the train to pass through the crossing without stopping.

VETAG or similar systems accommodate light rail vehicles (LRVs), essentially, by creating windows in signal timing during which LRVs can clear intersections without stopping and by actually accommodating trains within these timing windows so that street traffic is affected minimally.

Calgary and Los Angeles use ATSAC or similar systems. This system links intersections and uses a computerized optimization program to achieve the most efficient signal timing. The system detects the LRV's approach to a downstream intersection, and if LRT priority is programmed into the system, it will adjust the signal progression so that LRT trains can pass through the next crossing without stopping.

All other LRT systems operate at-grade crossing signals with standard controllers and detectors; timing is adjusted for extended green time on the LRT approach. San Diego has adopted a creative approach to using standard signal controllers to provide more efficient LRT priority using its signal phase countdown device for drivers, so that the LRV can cease boarding passengers and disembark in time to catch the green "wave."

No LRT systems were found to have true signal preemption capability at at-grade crossings in their CBDs. However, most downtown systems had instituted LRT train priority at crossings.

TABLE 2 Existing At-Grade Crossing Strategies

LRT System Location/Agency	Signal Control System	Agency Strategies Addressing LRT Movements
Baltimore (Maryland MTA)	Standard	Signals are timed to facilitate LRV progression at 5 mph. Bids being solicited to install signal preemption on Howard Street corridor to allow faster operation.
Boston (MBTA)	Standard; testing trolley indicator	No preemption, testing a "trolley indicator" which detects train at on-street station, triggers red phase at upstream signal to minimize auto conflicts with alighting passengers; early indications of low safety benefits, high street traffic disruption.
Buffalo (NFT Metro)	Standard; with VETAG	No congested CBD intersections; VETAG working satisfactorily to ensure LRV priority. Staff considers VETAG to be highly cost-effective for their system as opposed to an ATSAC-type system.
Calgary (Calgary Transit)	ATSAC	Satisfactory operation; ATSAC adjusts timing to facilitate LRT progression using its signal optimization function.
Los Angeles (MTA)	ATSAC operational in Long Beach segment; test phase in Los Angeles	Long Beach ATSAC facilitates LRV priority at minor CBD xings; no LRV priority at three major arterials, occasionally trains must stop (and some indications are that LRT operators may not be slowing as they encounter a yellow phase at these locations in order to maintain schedules). ATSAC not operational in Los Angeles segment.
Pittsburgh (Port Authority Transit)	Standard	No LRV priority or preemption. Actuators alert signal controllers on LRV approach; signals treat LRV movements the same as auto traffic.
Portland (TRI-MET)	Standard; with VETAG	VETAG seen as "win/win" strategy--train only affects signal timing upon departure from station. VETAG seen as cheaper, more reliable than ATSAC-type system.
Sacramento (RT)	Standard	Trolleys detected at intersection pavement loop; depending on the location, timing may give LRV priority. Where there are gates, trains must leave the station before they lift. Fire trucks can cancel LRT priority if needed.
San Diego (MTDB)	Standard, with "green wave" LRV progression	In "C" Street corridor, "countdown" device at initial xing allows LRV to depart at the early part of a green phase. Downstream signals are timed to allow an LRV "green wave" provided the train initially departs as planned. The countdown device also alerts the operator to lock the LRV doors to ensure on-time departure.
San Jose (SCCTA)	Standard	As LRV approaches downstream at-grade xings in the CBD transit mall, trains are detected approximately one block prior to their arrival at the xing. Signal controllers adjust timing to allow LRT to proceed without stopping.
St. Louis (Metro Link)	Standard railroad xing gates	Standard controllers detect LRT and close railroad xing gates upon approach.

Block Length and Other On-Street Issues

Most cities with constraints on train length due to short block lengths were able to increase capacity by increasing headways and avoid obstructing intersections by locating stations in those blocks that are of adequate length, as well as by granting priority to trains so that stopping at short blocks is unnecessary (Table 3).

However, at-grade operations are affected by CBD block length in three cities: Sacramento, San Diego, and Los Angeles. In Sacramento, four-car trains are deployed, even though incidents in which trains overhang into intersections occur. In Los Angeles, there is also a situation of overhanging trains at several intersections, even though train length is limited to two cars. Three-car trains will be necessary soon, which may cause more significant concerns with overhanging trains. San Diego designed its stations to accept overhanging trains; during peak hours MTDB must run a three-car configuration, and because since blocks fully accommodate only two-car trains, the three-car train extends into pedestrian crosswalks.

Shorter trains could mean capacity problems for LRT agencies facing anticipated growth in patronage and block length constraints on operations. In the short term, many systems intend to use shorter headways to cope with this problem, despite increased operating costs. In addition, some systems stated that both short- and long-term growth in transit patronage will be handled by increases in bus transit service.

TABLE 3 Existing Block Length Constraints

LRT System Location/Agency	Block Length Constraints?	Agency Strategies Addressing Block Length Constraints
Baltimore (Maryland MTA)	Yes	CBD block length limits LRT train length to 3 cars; current system operates 3-car trains.
Boston (MBTA)	No	Agency staff indicated no block length constraints.
Buffalo (NFT Metro)	No	Agency staff indicated no block length constraints.
Calgary (Calgary Transit)	No	No block length constraints; train platforms not located on short blocks in CBD. Train length is constrained by platform length to 3-car trains.
Los Angeles (MTA)	Yes	Block lengths are a problem for at least five xings in the Los Angeles street-running segment and two xings in Long Beach. Trains overhang intersections at these locations. At xings near Washington station, train overhang occurs. This situation is occurring with 2-car trains.
Pittsburgh (Port Authority Transit)	No	Agency staff indicated no block length constraints.
Portland (TRI-MET)	No	Some short blocks exist in CBD but trains do not stop; does not affect train length with current operations.
Sacramento (RT)	Yes	Block length a concem in some CBD locations, where 4-car trains do overhang intersections; peak train length is 4 cars. This situation is tolerated. Accidents have become a concem at other xings, however, due to on-street configuration. Staff has used curbs and median channelization, as well as signing and striping to alert auto drivers.
San Diego (MTDB)	Yes	Train length is limited in several CBD locations by block lengths of approximately 200 feet (can accommodate 2-car trains). Peak train length is 4 cars; prior to entering CBD, trains are shortened to 3 cars at a transfer station. Trains overhang intersections; pedestrian crosswalk traffic is blocked.
San Jose (SCCTA)	No	Agency staff indicated no problem with block length constraints; trains operate with 2 cars, station length limits trains to a maximum of 3 cars.
St. Louis (Metro Link)	No	Agency staff indicated no problem with block length constraints.

In the long term, many systems anticipate building new LRT lines to increase capacity, although this may create further pressure on at-grade crossing signals due to increased patronage on trunk lines.

Future At-Grade Crossing Issues

This section outlines the views given by agency staff on whether at-grade crossing issues would be an important consideration in the future and what, if any, actions they plan to take to resolve these issues (Table 4).

Whether shorter headways will cause future at-grade crossing traffic congestion appears to be a function of the level of new transit demand that will need to be accommodated. The following systems expect either short- or long-term pressure on existing at-grade crossings. Demand is expected to rise either solely on existing lines or because planned new feeder lines will place more pressure on existing CBD trunk lines.

The Los Angeles Metro Blue line is currently operating at capacity, running at a minimum headway of 6 min with two-car trains. Increased capacity is an imminent need. There are plans to go to 5-min headways within the next few years, and cars have been ordered that will allow trains to be extended to three cars. Without LRV priority at major Long Beach crossings and the Los Angeles street-running segment (where ATSAC is installed but not operating), this configuration could cause even more serious problems with overhanging trains than the current situation.

Pittsburgh LRT is also operating near capacity. The transit agency has issued a request for proposal for a consultant to analyze current demand and project future capacity and demand. Depending on results and new projections, at-grade crossing issues will be examined.

San Diego staff were concerned that on the C Street Line, feeder line extension plans could result in headways that degrade at-grade crossing operations in some CBD locations. The authors note that block lengths in the CBD on the C Street Line restrict train length to three cars in the peak hour (and this configuration results in trains blocking crosswalks). In the future, MTDB might have no choice but to run very short headways that would increase pressure on CBD at-grade crossings.

For San Francisco Muni, LRT at-grade crossing issues will begin with the opening of future Embarcadero (Muni Metro) and Market Street (F Line) LRT lines. Five-minute headways with preemption are initially planned. However, Muni officials stated that potential future operations may see 2- to 2.5-min headways, which would render at-grade intersection operations very tight and preemption difficult.

Similarly, Edmonton staff anticipate that in the long term, demand might affect at-grade crossings on the planned university area extension, which is located downtown.

Sacramento RT also plans significant growth in its LRT system. RT staff indicate that although the Phase 1 South Line extension will pose no problem, Phase 2 of the expansion plan includes the Natomas Line to the Sacramento Airport, which will further reduce headways and may increase pressure on the at-grade crossing traffic signal system downtown.

Portland staff indicated that in the future, the current LRT system may reach the capacity limits at at-grade crossings (this would occur when 3-min headways are running). This situation will arise because of planned downtown lines and line extensions (eight planned LRT lines in all).

Future At-Grade Crossing Strategies

As indicated, Los Angeles, Pittsburgh, San Francisco, Edmonton, San Diego, and Portland anticipate at-grade crossing problems in future because of anticipated increases in demand and system expansion plans.

Pittsburgh and Sacramento have not begun to discuss specific strategies. Pittsburgh intends to draft its plans soon, and Sacramento will wait until the Phase 2 Natomas extension to the Sacramento Airport, which is anticipated to degrade at-grade crossing operations, is closer to implementation.

Los Angeles, San Francisco, Portland, San Diego, and Edmonton are considering specific at-grade crossing strategies to address the at-grade crossing issues that will arise from operations expansion and line extensions. The following section outlines their planned approaches.

In Los Angeles, a working ATSAC system in the street running the Los Angeles segment is needed. In this segment, LRV priority is essential, especially at crossings where trains block intersections. At minor crossings in Long Beach, LRV priority is provided. However, at major crossings in Long Beach, there is no LRV priority and trains must stop; because of this, some LRT train operators are inclined to try to beat the red signal indication in order to meet operating schedules. Long Beach and MTA are discussing the need for some form of LRV priority at these crossings to solve this issue.

In San Francisco, with a strong local mandate to build traffic signal timing around transit, a VETAG system will be built. This may become obsolete after the first years of LRT at-grade operations. To replace it, Muni is considering an optical or infrared transmission system for buses and potentially for LRT. In Portland, Tri-Met staff stated that an aggressive rail-building program will increase the number of direct downtown rights of way by constructing new radial lines from the CBD; plans include eight new lines regionally. As lines reach capacity, there may be at-grade crossing concerns. They will run minimum headways using the current signal system and accommodate excess transit demand on the bus system.

Given their long-range LRT system extension plans, San Diego staff are looking into every possible option for the C Street Line operating in the CBD. Another look at how LRV priority is implemented or at a new CBD LRT crossing are possibilities.

In Edmonton the need for priority traffic signal systems for the university extension (which passes through the CBD) has not been finally determined, but LRV priority is a likely outcome. A decision will be made after the current phase of system expansion predesign is complete.

CONCLUSIONS AND PROPOSED POLICY CHANGES

Interjurisdictional Relationships

Good interjurisdictional relationships and agreements between cities and transit agencies are important for all of the LRT systems contacted.

TABLE 4 **Future At-Grade Crossing Issues and Strategies**

LRT System Location/Agency	Future At-Grade Crossing Issues	Future At-Grade Crossing Strategies
Baltimore (Maryland MTA)	Ridership may exceed current system capacity	Build more LRT line segments and absorb some transit ridership onto conventional bus system.
Boston (MBTA)	No anticipated future operations issues.	n/a
Buffalo (NFT Metro)	No anticipated future operations issues.	n/a
Calgary (Calgary Transit)	No anticipated future operations issues.	n/a
Edmonton (Edmonton Transit)	Future xing impacts anticipated on planned University area extension due to congested CBD intersections.	May consider LRV priority for this new line. Decision will be made after system predesign is complete and engineering work has begun (one year away).
Los Angeles (MTA)	Current system is at capacity (2-car trains, 6-minute headways). Increased capacity is an imminent need. Shorter headways will create further pressure on existing xings; 3-car trains are anticipated, however, short block length and lack of signal priority will create concem in Long Beach.	A working ATSAC system in the street-running Los Angeles segment is anticipated to assist with this near-term situation, extending priority to trains--this is critical at xings with trains overhanging. Train priority must be worked out with Long Beach at major xings to avoid trains stopping in short blocks; otherwise, passenger transfers from 3-car to 2-car trains may occur at Long Beach city limits.
Pittsburgh (Port Authority Transit)	As yet undetermined by agency; future LRT plans will be drafted in near future and strategies will be developed at that time.	n/a
Portland (TRI-MET)	Future system may reach capacity limits of at-grade xings (at 3-minute headways). This is due to planned downtown LRT lines and extensions (8 projects).	Aggressive LRT building program will increase system capacity, but may degrade operations at at-grade xings. Agency will run minimum possible headways, and anticipate that bus transit will absorb excess LRT demand.
Sacramento (RT)	Phase I South Corridor extension will reduce headways, but not enough to degrade xing operations. There is a possibility that headways may decrease further with the Phase II expansion (Natomas Line to airport), which may cause pressure on at-grade xings.	At one location on the future extension, underground operation may be necessary as site conditions preclude at-grade running. No other measures are planned.
San Diego (MTDB)	Ridership increase anticipated on CBD "C" Street line; staff feels that to operate at headways short enough to degrade xing operations would increase LRT operating costs unrealistically.	Headways will be shortened but constrained by available operating funds. 3-car trains will continue to operate despite overhanging at some intersections. Given LRT expansion plans, various options are being considered.

(continued on next page)

TABLE 4 (*continued*)

LRT System Location/Agency	Future At-Grade Crossing Issues	Future At-Grade Crossing Strategies
San Francisco (MUNI)	LRT at-grade crossing issues in CBD will commence with future Embarcadero (MUNI Metro) and Market Street ("F" Line) lines. Potentially, headways of 2- 2.5 minutes may be necessary, which would mean "very tight" xing operations.	Because there is a strong public mandate for transit, signal timing is built around bus transit at present, and is anticipated to accommodate future LRT lines. VETAG system in place for bus priority; after the first years of LRT at-grade operation, this may be obsolete. Looking into an optical or infrared transmission system for buses and LRT.
San Jose SCCTA	Increased ridership in downtown transit mall; line extensions are being planned. Xings are not considered a severe constraint; instead, track crossings at either end of the transit mall constrain SCCTA's ability to decrease headways.	Headways to be reduced to minimum possible to meet demand, but staff anticipates that they will not need to modify the signal system to accommodate the increased demand.
St. Louis (Metro Link)	After the year 2000, demand will require adding one car to the current 2-car trains, and headways reduced to 5 minutes, resulting in slightly longer gate down-time. Staff anticipates no xing problems.	Increased demand to be served with longer trains, increased frequency; signal modifications are not seen as necessary.

Typically, where there is little anticipated growth in regional traffic or light rail and where systems have been in place over a longer period, LRT agencies and cities have resolved at-grade crossing issues in the past, and city-agency relationships concentrate on operating and maintaining the crossing system.

A significant finding was that institutional relationships are most critical for those agencies in the first years of at-grade operation and for those where growth in regional traffic or expansion of the LRT system is anticipated.

Constructive working interjurisdictional relationships in new or growing systems appear to occur if there is significant regional political support for LRT transit (and transit generally). Portland is an excellent example of what can be done if the region makes a strong political commitment to transit.

Portland's practice of working with more resistant local jurisdictions to institute a LRT priority signal demonstration could be a model strategy for many cities to secure local support for LRT traffic signal priority.

It should also be noted that European and Canadian experience, and experience in San Francisco regarding bus transit priority, has shown that LRT and city traffic engineering functions work better to resolve at-grade operations issues if they are located under one political entity (usually city government).

Existing At-Grade Crossing Strategies

Most LRT agencies have found either VETAG- or ATSAC-type systems to be the most effective ways in which to implement LRT priority. Cost appears to be the greatest factor in the choice of technology. Cities with substantial investment in ATSAC-type systems generally add the at-grade crossings to the computerized system. However, cities without ATSAC-type systems have found that VETAG appears to be very cost-effective, accommodating LRT vehicles even at congested intersections without an adverse effect on vehicular traffic conditions while allowing LRT vehicles to avoid stopping. These cities have no plans to institute an ATSAC-type system.

Block Length and Other On-Street Issues

Block length problems are most acute if the affected systems anticipate expansion and patronage growth. In the short term, the only way that these systems can solve the need for greater capacity (without overhanging trains) is to increase headways or establish signal priority, or both, so that trains do not have to stop in short blocks. This would increase labor and other operating costs for the system.

With proper funding programs in place, long-term establishment of traffic signal priority for LRV and other at-grade infrastructure improvements (e.g., traffic signals, signs, gates, and geometrics) will allow increased LRV operating speeds. This may decrease or eliminate the need to meet new demand by implementing more expensive capital improvements (new lines or grade separation) or the need to incur higher operating costs by adding more LRT trains or buses to the system.

Future At-Grade Crossing Issues and Strategies

Systems that anticipate new transit demand and overall regional traffic growth will address that future demand by either augmenting operations (by increasing headways) or building new lines and new line extensions. For many systems, this increase in service levels will degrade operations at at-grade crossings significantly. Los Angeles, Pittsburgh, San Diego, Edmonton, Sacramento, San Francisco, and Portland staff indicated that plans to augment operations and build new lines and line extensions may cause problems at at-grade crossings.

Most systems that anticipate at-grade crossing problems due to either shortened headways on existing lines or LRT feeder line extensions are considering at-grade crossing traffic signals and other improvements. Currently no system is seriously considering grade separation of its present LRT operation where it exists in the CBD.

PROPOSED POLICY CHANGES

Improvements in at-grade crossing infrastructure (traffic signals, prioritization, gates, signage, and striping improvements) may, in many cases, be a cost-effective way to increase capacity, by increasing LRT operating speed and perhaps delaying the addition of trains or buses—at least in the short term. For a few systems, such at-grade crossing improvements might even obviate for the long term more trains or new lines. Even if at-grade crossing improvements do not delay or eliminate the need for LRT service increases and additional line segments, they may augment the capacity of the LRT system when implemented in conjunction with these strategies. The authors recommend that this potential be considered as part of the LRT system planning process.

A strong regional political commitment to transit is the key factor in implementing effective at-grade crossing infrastructure in growing LRT systems. The authors suggest that a key inducement for jurisdictions to achieve this political consensus should begin with a federal regulatory and funding commitment to at-grade crossing improvements. Modifications to the Intermodal Surface Transportation Efficiency Act of 1991 might serve as a future vehicle for a new federal funding initiative. In addition, state and local funding for these improvements should also be identified, in order to put the issue of at-grade crossing improvements on the table as LRT systems are planned.

The authors strongly suggest that LRT agencies and local cities begin to discuss seriously at-grade crossing issues in the preliminary planning process for LRT systems. A funding incentive program involving all levels of government would indicate a strong policy direction favoring consideration of at-grade crossing improvements. This could smooth the way for strong regional political commitment to, and success in, upgrading at-grade crossing infrastructure.

The authors suggest that the federal government, with its critical role in planning and funding LRT systems, should lead this initiative, with defined roles for states and local jurisdictions in the funding process. Upgrading at-grade crossings should become a vital part of the federal, state, and local discussions regarding LRT planning. If these discussions seriously consider at-grade crossing improvements in the initial planning stages, the potential exists for minimizing operating and capital costs and realizing safety benefits for the LRT system.

What could such a federal mandate look like? The authors suggest consideration of the following incentive measures:

1. A federal and/or state funding process that grants incentive funds for newly built systems that implement agreements between agencies and cities to install and maintain effective at-grade crossing infrastructure improvements. This measure is intended to promote more efficient LRT and street traffic operations. In this case, the federal incentive funds need to be granted to both city and LRT agencies and should have relatively few restrictions on transportation expenditure, in order that cities and LRT agencies subjectively consider the agreement-related incentive dollars as useful (which offers them a true incentive). This measure is designed to ensure that the LRT planning process includes consideration of at-grade crossing improvements that increase capacity and safety and reduce other operating and capital costs.
2. A federal and/or state funding process that provides the capital funding for LRT agencies to upgrade at-grade crossings to standards such as those being developed by the *Manual of Uniform Traffic Control Devices*, the California Traffic Control Device Committee, and ITE. This measure would ensure that up-to-date traffic signal systems, signage, gates, and geometric improvements are implemented, so that the highest available levels of system safety, capacity, and operating efficiency are guaranteed.
3. A federal, state, and/or local funding process that allows cities with bona fide agreements with LRT operators to maintain and operate the traffic signal system and, where the system safety record and on-time LRT performance meet a certain federal standard, to receive a subsidy for traffic signal system operations and maintenance costs. This measure is designed to ensure that cities and agencies agree on specific at-grade crossing improvements and to promote efficient system performance.

It should be noted that with federal funding programs that could be made available, concurrent state programs to secure matching funds (or primary funding, or both) for traffic signal and other at-grade infrastructure improvements should be clearly defined.

In conclusion, the authors wish to emphasize that funding incentives can place at-grade crossing infrastructure upgrades squarely within the initial planning LRT process. Availability of funding for at-grade crossing improvements would bring cities and agencies together to discuss seriously these cost-effective strategies. For successful implementation of LRT systems in the United States, leadership and a commitment to cooperation on this issue from LRT agencies and federal, state, and local government are required.

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PART 5

Ridesharing and Paratransit

Understanding Asian Commuters in Southern California: Implications for Rideshare Marketing

AMY M. HO

Asian Americans are the fastest growing segment of the U.S. population, more than doubling in the past decade from 3.7 million in 1980 to 7.9 million in 1990. Findings on the travel behavior and commuting concerns of the Asian-American commuter are based on an analysis of *State of the Commute* surveys conducted by Commuter Transportation Services, Inc. (CTS) in 1991, 1992, and 1993. Supporting data are taken from the 1980 and 1990 Censuses. CTS has also reviewed marketing literature for techniques that have proved effective in reaching the Asian-American market in other industries. It should be noted that within the Asian community, there is a wide range of ethnic groups that are diverse in many characteristics: language, religion, culture, and value system. Some general inferences made, therefore, may not apply to all Asian ethnic groups. Results show that Asian commuters have a higher drive-alone rate and a lower carpool rate than other ethnic groups. However, Asians are the most likely to indicate that they would be interested in trying carpooling or vanpooling. Marketing literature indicates that Asians concentrate in suburban strongholds and identify with their native language; marketing campaigns that are in Asian languages and that promote a sense of community have been effective. It is concluded that Asian commuters are likely to choose an alternative to driving alone if given more information on their commute options. CTS can increase the rideshare rate of Asian commuters by investing in marketing programs targeted at this group. The marketing campaigns should include home-end corridor programs and promotional material in Asian languages.

Although Asian Americans make up only 3 percent of the U.S. population, they have been the fastest-growing ethnic group, more than doubling in the past decade from 3.7 million in 1980 to 7.9 million in 1990. In the Los Angeles–Anaheim–Riverside Consolidated Metropolitan Statistical Area (CMSA)—Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties—Asian Americans have increased by 54 percent, from 600,000 in 1980 to 1.3 million in 1990, now representing 9.2 percent of the population (Figure 1).

Asian-American market research has been limited to studies of small sample sizes and has been lacking in an understanding of Asian values. Companies are not willing to invest in the high cost of researching a market that is complex because of its diversity in language and dialect. As a result, there is currently little marketing information about the Asian community.

Commuter Transportation Services, Inc. (CTS), a private, nonprofit corporation dedicated to helping commuters find alternatives to driving alone, has developed this paper to determine the extent to which rideshare marketing efforts have reached this race group and how to improve or develop more effective rideshare marketing programs.

More specifically, this paper has been prepared to answer the following three questions:

1. Who is the Asian commuter market, and what are the characteristics and profile of its members?
2. What is the travel behavior of Asian Americans? How do they travel to work? What are their commuting concerns?
3. How do we market to Asian Americans? What messages and media do we use?

DATA SOURCES

Findings in this paper are taken from the 1991, 1992, and 1993 *State of the Commute* surveys conducted by CTS and the 1980 and 1990 Censuses. In addition, the marketing literature has been reviewed to provide insight on the most effective marketing strategies in other industries.

The *State of the Commute* surveys provide travel behavior data and some demographic information. Data for the studies were collected via telephone interviews among commuters who are 18 years or older, work full-time outside their homes, and reside in Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties. For the 3 years combined, a total of 7,671 commuters were surveyed, of which 7 percent were Asian (543 respondents). Responses are weighted by the number of respondents in each race group for that given year. This ensures that the race groups with larger sample sizes for a given year are not overrepresented. Data are also weighted by county populations based on the 1990 Census figures to ensure that less populated counties carry a weight in proportion to their share of the regional population.

Although 1990 Census data may be more reliable than the *State of the Commute* survey results, the Census data do not provide summary totals for the selected variables by race. The Public Use Microdata Sample data of the 1990 Census can provide this information, but the *State of the Commute* goes into more detail regarding commuting behavior and attitudes.

This paper summarizes characteristics of the Asian market. The Asian group identified encompasses a wide range of ethnic groups, (i.e., Japanese, Chinese, Korean, Filipino, Vietnamese, Asian Indian, and Pacific Islanders). It should be noted that these groups are diverse in many characteristics—language, religion, culture, and value system—and some general inferences may not apply to all groups.

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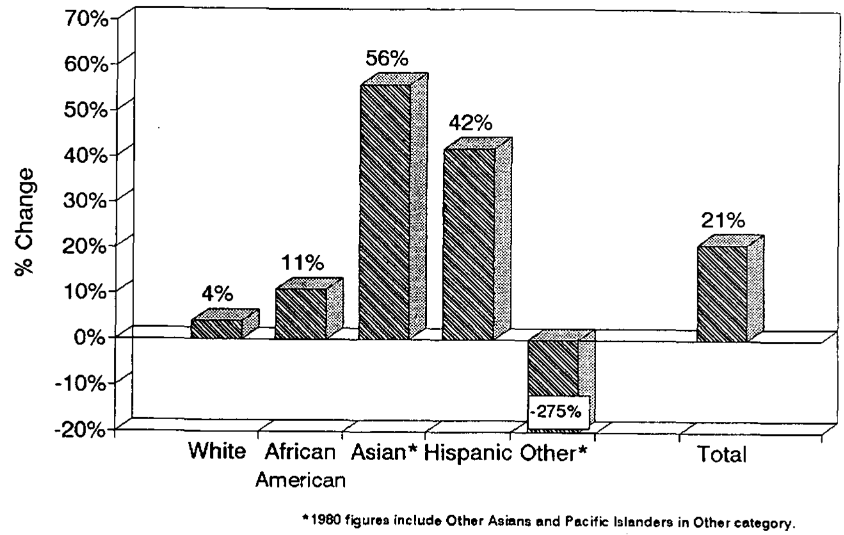

FIGURE 1 1980–1990 percentage change (*1*).

DEMOGRAPHIC CHARACTERISTICS

Size of Ethnic Groups

According to the 1990 Census, 1.3 million Asian Americans reside in the Los Angeles metropolitan area (Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties); Asian Americans make up 9 percent of the regions's population of 14.5 million. The largest Asian ethnic group in this region is Chinese, followed by Filipinos (Figure 2).

Age

According to respondents in the *State of the Commute* study, Asian commuters residing in the Los Angeles basin are younger than non-Hispanic whites and African Americans. Seventy-seven percent of Asian respondents are under 40 years old; only 59 percent of non-Hispanic whites are under 40. The youngest race group is Hispanics, 87 percent of whom are under 40 years old.

Income

The annual household income for Asian commuters in the Los Angeles CMSA is higher than that of African Americans and Hispanics but lower than that of the non-Hispanic whites. Thirty-one percent of Asian commuters have household incomes of $65,000 and up, whereas only 20 percent of African Americans and 9 percent of Hispanics commuters have household incomes of $65,000 and up. Non-Hispanic whites have the highest household incomes; 36 percent have household incomes of $65,000 and up.

Occupation and Work Site Size

Asian and non-Hispanic white commuters have similar breakdowns in occupation fields. The occupation most often reported is professional, followed by sales and service.

Most non-Hispanic whites, Hispanics, and Asian Americans (65, 70, and 62 percent, respectively) indicate that they work at sites with under 100 employees. Half of African Americans indicate that they work at work sites with under 100 employees.

Length of Time at Work/Home Location

Asian commuters report the shortest length of time at their current work location, 47 months (4 years), and non-Hispanic whites report the longest, 65 months ($5^1/_2$ years). African Americans and Hispanics report similar lengths of time at their work locations, 54 and 53 months, respectively.

Asian commuters also report the shortest length of time living at their current home location, 70 months (5.8 years), whereas non-Hispanic whites report the longest length of time, 88 months (7.3 years). African Americans and Hispanics have an average length of time at their home locations that is slightly longer than Asians, 72 and 76 months respectively.

Number and Availability of Vehicles

According to the *State of the Commute* data, all Asian-American commuters interviewed have a vehicle in their households, whereas 4 percent of Hispanic households do not have a car and 3 percent of African-American commuters do not have a car in their households.

In addition, 90 percent of Asian commuters always have a car available to commute to work, compared with only 79 percent of Hispanics and 85 percent of African Americans. Of all groups, non-Hispanic whites are most likely to always have a car available for commuting (94 percent).

TRAVEL BEHAVIOR

Travel Mode

For their primary mode of transportation (3 or more days a week), 86 percent of Asians drive alone to work. This drive-alone rate is

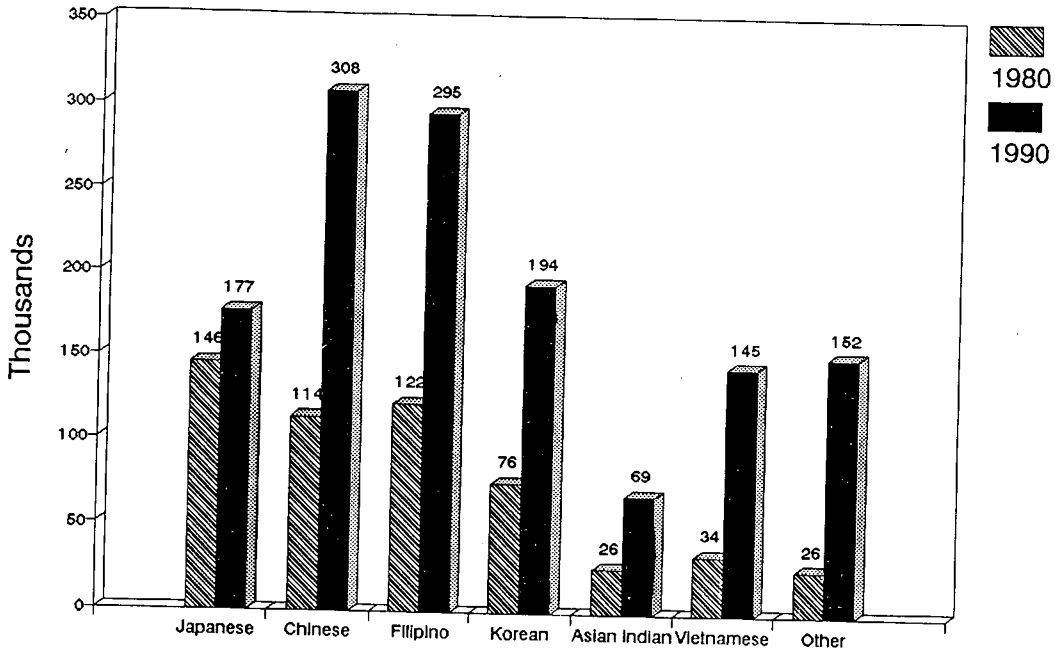

FIGURE 2 Population growth by Asian groups (*1*).

the highest of the race groups; 2 percentage points higher than non-Hispanic whites, 13 points higher than African Americans, and 21 points higher than Hispanics (Figure 3). The Asian carpool and transit rates are the lowest of all race groups, 11 and 1 percent, respectively (Figure 4).

Averaged over the past 3 years, only 22 percent of Asian commuters rideshare full-time (3 or more days a week) compared with 29 percent of non-Hispanic white commuters, 36 percent of African-American commuters, and 42 percent of Hispanic commuters. However, a larger share of Asian commuters rideshare part-time (1 or 2 days a week): 10 percent of Asians rideshare part-time but only 6 percent of non-Hispanic whites, African Americans, and Hispanics.

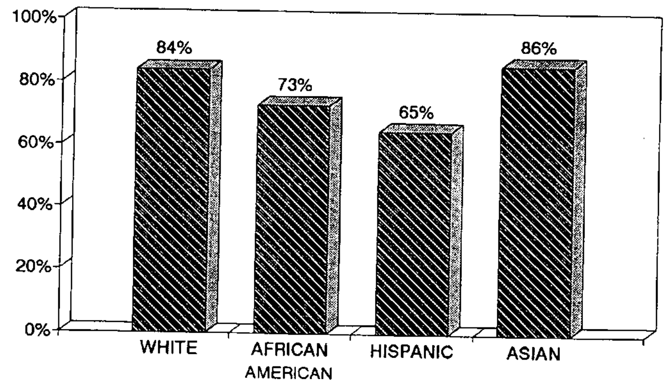

FIGURE 3 Drive-alone rate by race (*2*).

Commuting Time and Distance

The average commuting distance for Asians is 15.1 mi, shorter than the commuting distance for non-Hispanic whites (16.7 mi) and African Americans (16.1 mi) but slightly longer than the commuting distance of Hispanics (14.7 mi) (Figure 5).

Although the average distance traveled by Asians is shorter than the distance traveled by the other groups (except for Hispanics), the average self-reported travel time to work, 31 min, is comparable to that of the other race groups (Figure 6).

Arrival and Leave Time

Asian commuters, on average, arrive and leave approximately 30 min later than commuters from other race groups. Hispanic commuters arrive and leave the earliest. On average, non-Hispanic white commuters work longer days than commuters of the other race groups, 12 min longer per day.

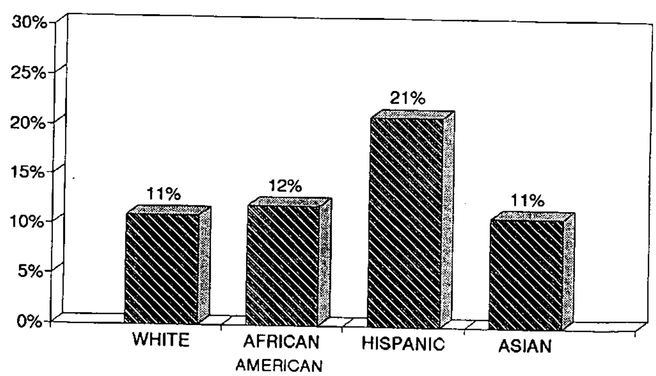

FIGURE 4 Carpool rate by race (*2*).

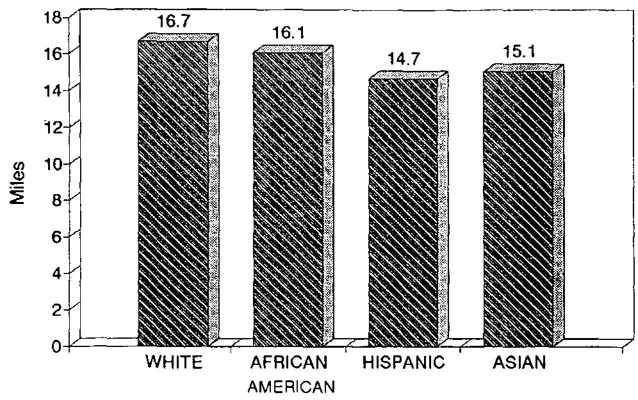

FIGURE 5 Distance to work (2).

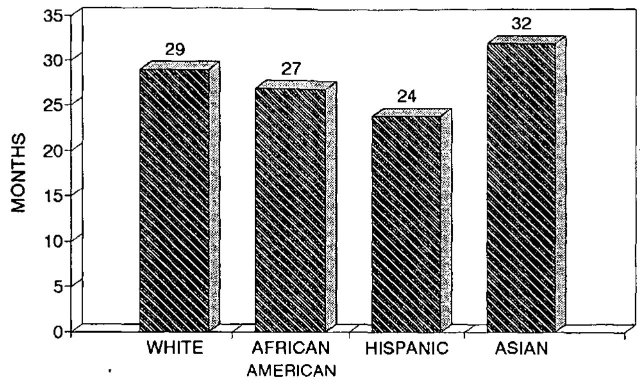

FIGURE 7 Number of months in carpool (2).

Carpooling Characteristics

Carpool Size

The average carpool size for Asian Americans (2.56) is smaller than that for African Americans (2.98) and Hispanics (2.89) but larger than that for non-Hispanic whites (2.50).

Number of Months in a Carpool

Asian-American commuters stay in a carpool longer than do the other race groups, an average of 32 months (2.7 years), 3 months longer than non-Hispanic whites, 5 months longer than African Americans, and 8 months longer than Hispanics (Figure 7).

Carpool Partners

Household members are the most common partners for Asians who carpool. Thirty-seven percent of Asians who indicated that they carpool said that they carpooled with a household member. The most common carpool companion for non-Hispanic whites and Hispanics is also a household member. However, a co-worker is the most common carpool partner for African Americans.

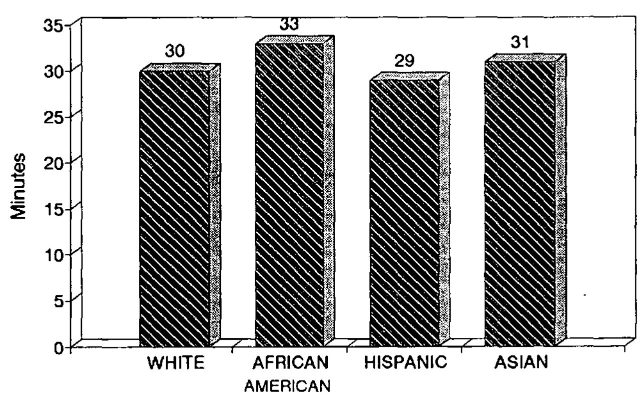

FIGURE 6 Travel time to work (2).

Unlike the other race groups, Asians indicate friends and neighbors as the second most common type of carpool partner, 25 percent. For all other race groups, the two most common carpool partner types are household members and co-workers.

The high propensity for Asian commuters to carpool with household members and friends and neighbors can explain the longer life expectancy of their carpools. Carpool arrangements with family and friends tend to be more convenient and permanent. Similarly, carpool arrangements with someone from a matchlist would more likely be short-lived because individuals are less committed. Hispanics are the most likely to carpool with someone from a matchlist, 15 percent, and their carpools have the shortest life expectancy.

Commuter Attitudes

Satisfaction with Commute

When asked to rate their current commute to work from 1 to 9 (1 being least satisfactory), the average rate for Asian respondents is 6.2. Although the average rate for Asian respondents is comparable to that of the other race groups, Asian commuters are less likely to rate their commute a 9. Only 14 percent of Asian commuters rate their commute a 9 compared with 17 percent for non-Hispanic white commuters, 18 percent of Hispanic commuters, and 20 percent of African-American commuters.

Factors in Selecting Mode

When asked what they consider in choosing a travel mode, the most common response for Asians is convenience and flexibility (29 percent) followed by travel time to work (20 percent). These two factors are also the most common for the other race groups. However, although 18 percent of Hispanics and 16 percent of African-American commuters indicate "no other way," only 10 percent of Asian commuters report this factor.

Consider Ridesharing on Trial Basis

When asked whether they would consider carpooling on a trial basis once or twice a week, 25 percent of Asian respondents say that they would definitely try it. This percentage is the highest for the four ethnic groups; only 16 percent of non-Hispanic white commuters say that they would definitely try carpooling, 20 percent of Hispanic commuters, and 22 percent of African-American commuters.

Asian-American commuters also respond more favorably to vanpooling. Twenty-four percent of Asians who commute 20 mi or more one way say they would definitely consider vanpooling; this compares with only 11 percent of African Americans, 14 percent of Hispanics, and 18 percent of non-Hispanic whites (Figure 8).

However, when asked if they would consider riding the bus to work, Asians respond similarly to the other race groups. Only 7 percent of Asian commuters indicate that they would definitely try riding the bus, 6 percent of non-Hispanic whites, and 9 percent of both African Americans and Hispanics.

Recognition of Commuter Computer

Of the four race groups, Asians rank second to last in having heard of the "Commuter Computer" or the RIDE-number. Non-Hispanic whites rank first, African Americans second, and Hispanics last.

As expected, Asian commuters are the least likely to have contacted Commuter Computer (7 percent), compared with 11 percent for non-Hispanic whites and 9 percent for African Americans and Hispanics.

MARKETING AND ADVERTISING STRATEGIES

General marketing literature on the Asian market was reviewed to learn more about strategies that can be applied to the development and design of an effective rideshare marketing program.

Urban Concentration

Most Asians live in metropolitan areas where housing costs are high. Within these metropolitan areas, the urban concentration of Asians are suburban strongholds such as Monterey Park and Daly City. New Asian immigrants first move to affordable urban neighborhoods where they save money and later move out to wealthier communities, which usually means longer commutes.

Because Asians tend to be concentrated in selected suburban communities, marketing campaigns can be geographically focused on these Asian-dominated neighborhoods.

Accessibility

Accessibility is a valued quality for the Japanese; convenient transportation is one of the most important factors in selecting a home location. For example, in Japan, houses are advertised by their distance to the train station.

State of the Commute findings support these values as true for Asians living in Southern California. Survey results show that Asians tend to have short commutes. Short commutes mean that living close to work may play an important role in the selection of a home or work location.

Technical Orientation

Because Asian Americans are younger and more educated, they tend to be more comfortable with technology: having technical occupations and owning home computers, sophisticated car alarms, and other electronic equipment. As the transportation field advances, Asians may be an appropriate market for technically oriented programs: touch-screen ridematching booths, debit card systems, intelligent vehicle-highway systems.

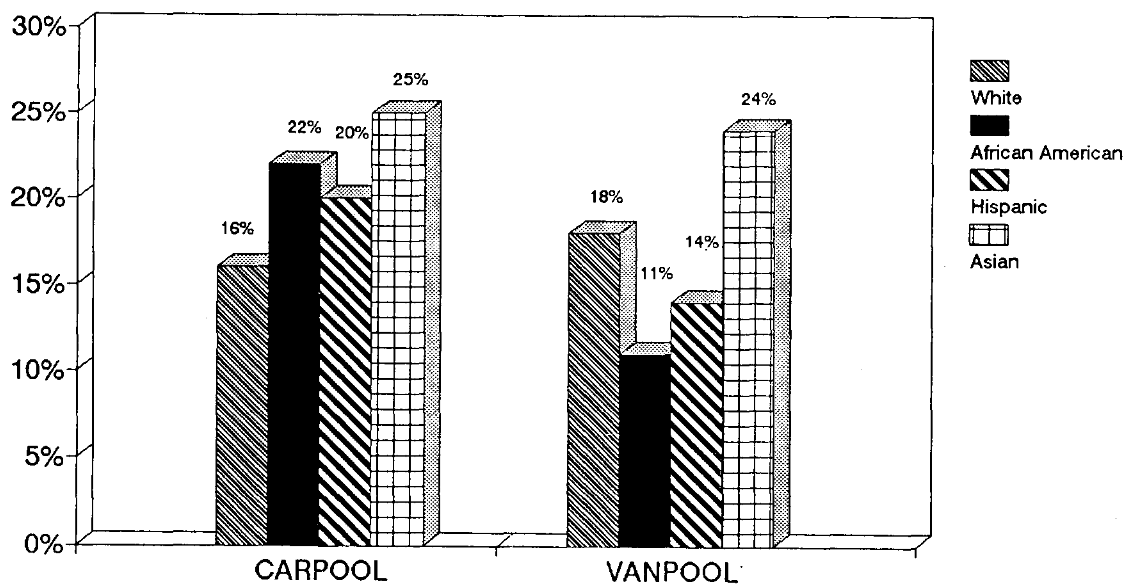

FIGURE 8 Consider carpooling or vanpooling (*2*).

Language

Language plays an important role in doing business with the Asian-American community. For example, even second- and third-generation Asian Americans use San Francisco's *Asian Yellow Pages* as a way to "maintain their community." In fact, approximately 5,500 businesses advertise in the *Asian Yellow Pages,* which earned more than $5 million in 1989.

One proven method of reaching the Asian market is to use their native tongue. Television advertising may not be as cost-effective as the newspaper. In fact, the newspaper is currently the most widely used media for targeting the Asian market.

Diversity

Different Asian Race Groups

Asians may be the most difficult race group to target because of the diversity among the different ethnic groups. Researching the differences of each Asian ethnic group may be costly but critical in successfully reaching the Asian communities.

First and Second Generations

In addition to the diversity within the Asian group, there exists a diversity among the generations: between new and assimilated Asian Americans. When marketing to multiple generations, the use of both English and the Asian language can be important in bridging the age gap.

There is also a difference between newly immigrated Asians and second-generation Asians. Newly immigrated Asians face unique problems—language, long workdays, and underemployment (where college-educated persons drive taxis and work in convenience stores)—that segregate them from Asians who have assimilated into the American culture. It may be difficult to reach both groups with the same marketing promotion. For example, new immigrants may prefer longer hours of bus service whereas second-generation Asians may prefer more frequent bus service during peak hours.

CONCLUSIONS

The findings from this paper show that Asian commuters have many similar demographic characteristics and travel behaviors to the non-Hispanic whites. From these findings, it can be assumed that CTS can reach the Asian community through general marketing campaigns that target the non-Hispanic white population. However, survey results also indicate that CTS has not reached Asian commuters compared with commuters of other ethnic groups; Asians

- Rank second to last in the recognition of Commuter Computer;
- Are the least likely to have contacted CTS in the last year;
- Have the highest drive-alone rate and the lowest carpool rate, although Asian carpoolers report the longest carpool longevity; and
- Are the most likely to indicate that they would definitely try carpooling, and those traveling 20 mi or more are the most likely to indicate that they would definitely try vanpooling, on a trial basis once or twice a week.

Given that Asians are the fastest-growing race group, nationally and regionally, and are more than likely to have access to a vehicle, CTS needs to invest in marketing alternative means of transportation to this race group. In addition, this group is young and educated, meaning that they will be making up a significant proportion of the future work force.

However, CTS needs to take caution in developing marketing campaigns that try to reach all segments of the Asian population. Like other immigrants, Asians have different transportation needs depending on how long they have been living in the United States. First-generation Asians tend to live near the central city and have short commutes, whereas second-generation Asians tend to live in suburbs with longer commutes. In selecting the target audience for rideshare promotions, CTS may find that public transit will be easier to market to first-generation Asians and carpooling or vanpooling will be more appropriate for second-generation Asians.

RECOMMENDATIONS

This paper recommends the following marketing strategies and programs:

- Home-end corridor programs in Asian enclaves. Because Asians tend to concentrate in suburban strongholds, marketing campaigns can be geographically focused. For example, CTS can conduct a corridor promotion along Atlantic Boulevard in Monterey Park. Atlantic Boulevard is a frequented thoroughfare in the Chinese community because many popular restaurants and retail establishments are located along this major arterial.
- Part-time rideshare promotions. Asian commuters prefer carpooling on a part-time basis, 1 or 2 days a week. Promoting part-time ridesharing can be the first step in reaching these commuters who usually drive alone to work.
- Marketing campaigns in Asian languages. Marketing campaigns should be developed in Asian languages. In addition to reaching those newly immigrated Asians, using Asian language will contribute a sense of community, which is an important Asian value.
- Pilot programs of technically oriented projects. CTS should solicit Asian-dominated communities to participate in demonstration programs that test the viability of using technically advanced equipment to reduce air pollution and congestion or improve mobility.

CTS can introduce two advancing projects involving high-tech equipment—touch-screen kiosks and the congestion pricing debit cards—to the Asian business community. Asian commercial districts may be good candidates for these projects because of their high densities and interest in trying new automated equipment.

- Investigate joint projects with Asian marketing firms. These companies are eager to explore new ventures and can provide helpful information about the Asian market. Specifically, CTS can work with Asian Business Connection—a growing telemarketing company that specializes in marketing to the Asian community—

to promote ridesharing to the Asian commuters. Asian Business Connection has a telemarketing staff that speaks Chinese, Korean, Japanese, and Vietnamese and a data base of a quarter of a million Asian households. With these two valuable resources, CTS can develop a powerful marketing campaign that will reach many Asian commuters.

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Employer-Provided Transportation Benefits, Public Transit, and Commuter Vanpools: A Cautionary Note

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The Comprehensive National Energy Policy Act of 1992 and Clean Air Act Amendments of 1990 create a new climate for ridesharing including the use of public mass transit. Under current operating conditions, certain bus routes may be at a competitive disadvantage to newly encouraged vanpool operations. The results of a study into the underlying reasons for commuting choices among public transit, carpools, and vanpools are reported. A set of hypothesized alternative situations involving realistic commuting costs and incentives based on the acts are developed. All participants in the study are currently public transit or carpool commuters. The research design uses the stated choice approach to disaggregated discrete choice analysis. A multinomial logit equation is fitted to the choice responses taken from the population of transit-carpool users at the study site. The results show that a $1.00 subsidy is required for transit to equal the utility found in an $0.83 vanpool subsidy. The latent demand for carpools and vanpools is demonstrated by the transfer penalty that ranges from $0.91 to $2.02 against transit for each transfer required to be used. When an effective transportation coordinator program at the employment site is combined with the maximum permitted tax-free employee benefit, the results show a decline in the use of transit by current users from 75 percent of the employee sample to 50 percent. Although the model does not show the propensity to form successful vanpools, there is nonetheless clear potential for a significant loss in transit ridership devolving from the successful implementation of both federal acts.

The Comprehensive National Energy Policy Act of 1992 provides an expanded commuting subsidy program for transit and vanpool users. The subsidy is a direct incentive to encourage the use of vanpools or public transit. Title XIX of the National Energy Policy Act permits employers to give employees a tax-free subsidy of $60/month. The subsidy is designed to aid regions in meeting the employer trip reduction requirements found in the U.S. Clean Air Act Amendments of 1990.

The subsidy amounts to an effective change in price for commuting services when using one of the qualifying modes. The congressional intent in both acts is to strengthen the use of alternative commuting modes as opposed to the single-occupant vehicle. The acts assume that both alternative modes will benefit from the price decrease; nothing is stated in either act regarding modal shifts occurring between the alternatives. Where public transit has the same level of underlying attractiveness to commuters as vans, no net loss in ridership will occur. However, when the marginal valuation of transit as currently used is less than that perceived for vanpools when made available, transit will experience a drop in ridership and the outright loss of trips and perhaps routes.

The research reported in this paper focuses solely on the potential loss of existing ridership devolving from the joint operation of the Clean Air Act and the National Energy Policy Act. The research does not address the overall or net impact derived from the growth of new transit ridership. Neither does it judge the ultimate economic efficiency for individuals in making the switch to vans from transit. Instead, it takes a transit system approach in which the present ridership is valued at a higher rate than the uncertain future ridership. The study will estimate the marginal rates of substitution for attributes, including the transit and vanpool subsidies, transfer penalty, and valuation of time saved. It concludes with a projection of the impact on existing transit ridership contingent on the implementation of a van subsidy program comparable to that received by transit.

RESEARCH DESIGN

The method used to measure the mode shift potential within the combined Energy and Clean Air Acts is the stated choice approach to discrete choice analysis (*1*). The method was chosen because of its ability to experimentally control the independent policy variables and its relatively efficient use of research resources (*2*). The target population selected for study consists of employees working at the Technical Center operated by the Port Authority of New York and New Jersey. The employees chosen for this part of the study currently use either public transit for the major portion of their commute or carpool to the site.

The data generation instrument was designed through a series of three focus groups held at the employment site. Each focus group contained at least 12 employees selected at large from the employees located at the site. Participants in the focus group sessions were asked to describe in detail their current commutes and previous experience with carpools, vanpools, or public transit and then to pilot test a draft survey instrument. After the draft survey instrument was completed, a critical review of the content and format of the document was held. Following the incorporation of the focus group findings into the draft survey instrument, simulation studies based on the new or accepted attributes and values were held to ensure that the range of values selected for the independent variables were capable of recovering hypothesized marginal utilities using the standard multinomial logit model (*3*). Finally, pilot tests of the penultimate instrument were run in order to ensure that employees understood the questionnaire and that fatigue and policy response bias could be controlled.

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The stated choice elements of the study consisted of 16 randomly ordered hypothetical choice tasks. Copies of the survey instrument are available from the authors on request. Employees chosen to complete the instrument were instructed to view each task as realistic future options for their commute. Each task gave employees the choice of three commuting options: using public transit, carpooling, and vanpooling.

DESIGN ATTRIBUTES

Two classes of attributes identify the commuting alternatives: constants and mutually orthogonal independent variables (*4*). Public transit was defined as public or private transit vehicles operating on fixed routes and schedules whose vehicles drop off the commuter within walking distance of the work site. The definition includes transfers to shuttle buses operated by the employer. Each employee was asked to assume that the fare and commuting time for their transit trip will remain at their current levels across all choice tasks found in the experiment. That is, transit fare and trip time are constants. Two independent variables complete the set of design variables for the transit alternative: a company-paid transportation fringe benefit and a guaranteed-ride-home program.

The transportation fringe benefit was defined as a tax-free payment valued at up to $3.00/day that must be used on public transit. The guaranteed-ride-home program is defined as one that is available only to transit and certified vanpool users. The program generates transport services when the employee is faced with an emergency either at home or at the office, or when a supervisor asks an employee to stay late and miss normal commuting connections. The program is qualified with the time delay in order to reduce the tendency on the part of respondents to interpret it as identical to their personal car. To use the service, employees are required to be prequalified, to make the telephone contact with an approved car service company, and to make the payment at the end of the trip. The employee will be reimbursed through the employer's transportation coordinator. The guaranteed-ride-home variable assumes one of three values throughout the choice tasks: none, a program that adds 5 min to the regular trip time, and a program that adds 25 min to the regular trip time. The employment site currently does not have a guaranteed-ride-home program for its employees.

The carpool alternative is defined as a commuting arrangement among two to six employees in which one employee's vehicle is used for the commute. Six variables are used to depict the carpool option to respondents. Carpool costs are implicitly built into the experiment. Respondents are instructed to identify out-of-pocket costs such as those for gas, tolls, and parking charges. No maintenance, depreciation, or insurance costs are to be considered in the cost-sharing arrangement. The out-of-pocket costs are assumed to be shared equally by all of the members of the carpool. Current carpool arrangements at the site have on average 2.3 persons per vehicle. From this finding and the desire to keep the model relatively simple, the value of out-of-pocket costs assigned to each carpooler in the choice tasks was constant, set at half the individual's drive-alone costs.

The second identifier for the carpooling option is the rideshare subsidy. Throughout this experiment, the respondents were told that no subsidy would be available for carpoolers. The third and fourth identifiers for the carpooling option reflect what may become a new parking management strategy at the employment site. Parking at the site will be free to carpoolers, and reserved parking will be available for certified carpoolers in protected lots within a 5-to 10-min walk from their work site.

All forms of ridesharing are given the same guaranteed-ride-home options that were defined for the transit users; therefore, each choice task in the experiment shows respondents the same value for the guaranteed ride home variable across all commuting options. The sixth carpool identifier specifies the time spent commuting by carpool in contrast to that spent commuting by the public transit alternative. Focus group meetings aided in establishing the range of values. The values are expressed as the time in minutes saved one way using the carpool over that spent on transit; they are 15, 25, and 55 min.

The third commuting option is vanpooling. It is defined as an arrangement among seven or more employees sharing a leased van. The employee vanpool is responsible for the lease payments as well as the operating costs. The choice tasks show the vanpool costs to be a constant $3.00/person/day. It must be recognized that this value, while feasible, is optimistic. Assuming a $900/month cost for the lease, insurance, and maintenance fee, each van will require 16 employees to subscribe in order to meet the fixed costs. The employee payment will leave $108/month for fuel costs.

The vanpool alternative has an independent but comparable qualified transportation fringe benefit, as does the public transit alternative. As with the transit alternative, the values range from $0.00 to $3.00/day. Employees choosing the vanpool alternative will be presented with the identical guaranteed ride home as shown in the other two commuting alternatives. As with the carpool option, two parking management policies are incorporated in the choice set design; these are parking charges and parking availability. Both policies enter the model as constants. Employee vans park at no charge and are given preferential parking in spaces either under or immediately next to their work sites. The walk to work from these spaces takes roughly 3 min.

The final design attribute identifying the vanpool alternative is travel time relative to transit time. Focus groups were again used to establish a range of realistic values for the experiment. The values were entered as the minutes saved using a vanpool for the commute instead of public transit. The time savings ranged from 5 to 20 min. Note that in most cases carpools save more time over public transit than do vanpools.

ANALYTICAL MODEL

The commuting decision is modeled as a rational process. Each commuter chooses one of the three commuting alternatives on the basis of the explicitly or implicitly stated costs and benefits shown in each choice task. The costs and benefits shown in each choice task form the design attribute subset of independent variables. An orthogonal fractional factorial design was used to select the values of the design variables. The second subset of independent variables consists of socioeconomic, demographic, and attitudinal indicators. Each stated choice made by an employee is combined with a comparable set from the other employees in the sample to form a multinomial dependent variable.

The underlying analytical model describing the outcomes of the commuting decision-making process is the multinomial logit (*5*). The model combines the discrete decisions of individual commuters into a choice probability for each alternative. The fundamental assumption underlying the use of this model is Luce axiom: independence of irrelevant alternatives. For the multinomial logit to be the basis of unbiased estimators, it is assumed that the ratio of the probability of choice for any two alternatives is independent of all other alternatives.

The multinomial model is

$$P_i = \frac{e^{V_i}}{e^{V_i} + e^{V_j} + e^{V_k}} \quad (1)$$

where P_i is the probability that an individual $\{n\}$ in the target population will choose one alternative from a choice set containing alternatives $\{i, j, k\}$, and V_i, V_j, and V_k represent a linear in parameters indirect utility function for each alternative (*6*). The indirect utility functions are shown in Equation 2.

$$\begin{aligned} V_i &= \alpha_0 + \alpha_1 X_1 + \ldots + \alpha_m X_m + \epsilon_{i,n} \\ V_j &= \beta_0 + \beta_1 Y_1 + \ldots + \beta_m Y_m + \epsilon_{j,n} \\ V_k &= \gamma_0 + \gamma_1 Z_1 + \ldots + \gamma_m Z_m + \epsilon_{k,n} \end{aligned} \quad (2)$$

The set of coefficients $\{\alpha, \beta, \gamma\}$ represents the alternative specific constants, the marginal utilities assigned by commuters to each design attribute, and the shifts in the alternative specific constants generated by individuals through their socioeconomic and attitudinal indicators. The coefficients $\{\alpha_m, \beta_m, \gamma_m\}$ are interpreted as marginal utilities linking a change in one unit of an attribute $\{X_m, Y_m, Z_m\}$ to the change in utility experienced by individual n, holding income constant. Given that the index of utility $\{V\}$ is not directly observed, only the signs of the coefficients have theoretical relevance. The coefficients provide insights into commuter behavior when they are treated as measures of goods or services that can be substituted for each other. Under the conditions shown in Equation 3, that an individual is to maintain a constant level of utility, Equation 4 shows that the ratio of any two marginal utilities taken from the set of utility equations provides an estimate of the marginal rate of substitution (MRS) of one attribute in terms of another.

$$\frac{\partial V_i}{\partial X_k} dX_k + \frac{\partial V_j}{\partial Z_k} dZ_k = 0 \quad (3)$$

$$-\frac{dZ_k}{dX_k} = \text{MRS}_{x \text{ for } z} = \frac{\partial V_i/\partial X_k}{\partial V_k/\partial Z_k} \quad (4)$$

The coefficients are estimated through the use of the maximum likelihood procedure. The multinomial model will produce asymptotically unbiased estimators under two conditions: first, the scaling factor linking real-world behavior to stated-choice behavior is known, and second, that the deviations from the utility functions occur because of random individual choice variations (*7*). The set of socioeconomic, demographic, and attitudinal indicators is used to control for aggregate patterns of like behavior found within the sample. The variables used for this purpose include household income, gender, current use of public transit, number of transfers currently needed for the journey to work, means used to get from home to the transit stop, and various measures of distance or time traveled to work.

The multinomial logit model is based on various assumptions; the basic among these is the property of independence of irrelevant alternatives (IIA). This property implies that if some alternatives are removed or added to the choice set, the ratio of the choice probabilities in the new choice set remain unchanged (*8*). Essentially, this assumption requires that the alternatives presented to decision makers be substantially different from one another. If the IIA property is found to be violated, then suitable changes must be made to remedy the violation; failure to remedy the violation will then require the use of alternative model forms such as the nested logit (*9*).

The simplest test for IIA amounts to a comparison of the standard errors of the common variables across two logit models. The first model is the unrestricted model in which all alternatives are entered into the logit equation. The second model is a restricted model in which one of the available alternatives is removed from the choice set. A comparison of the estimated marginal utilities and their standard errors showed that in no case were the differences between marginal utilities for the unrestricted and restricted models greater than one standard error. The hypothesis of IIA was therefore not rejected.

EMPIRICAL RESULTS

The sample of observations is taken from a larger study of commuting behavior undertaken at the Technical Center of the Port Authority of New York and New Jersey in Hoboken, New Jersey. The study was performed in two stages. The first stage consisted of a general employee transportation survey. Data generated from this survey produce estimates of the site's average passenger occupancy level, each employee's revealed preferences for commuting mode, and attitudes toward commuting alternatives. The second-stage survey instrument consisted of a set of choice tasks. Public transit and carpool users formed the target population for the survey.

Table 1 presents the socioeconomic characteristics of the employees taken from the transit and carpooling sample. Males represent three-quarters of the sample, and the average annual household income is \$50,000 to \$75,000. Approximately 80 percent of the sample use public transit for the main part of their commute, 10 percent occasionally use transit, and 7 percent never use transit. The sample was selected on the basis of transit or car- and vanpool use; therefore, 20 percent of the sample use car- or vanpools for their trips to work.

Last, the respondents were asked several questions about either their actual transit trips or their most recent commuting trips via public transit. The average respondent was found to use 2.5 transfers per one-way commute to work, and the average total transit cost is \$4.15; the average time required to go from home to the bus stop in order to start the journey to work was 12 min.

ANALYTICAL RESULTS

The multinomial logit equation fitted to the sample is presented in Table 2. Each of the three commuting alternatives has a separate indirect utility equation. When combined according to Equation 1, the mode choice probabilities are recovered. Only those variables that obtain a *t*-score within the 5 percent significance level and whose signs are theoretically correct are retained for the final

TABLE 1 Characteristics of Employee Sample from Technical Center of Port Authority of New York and New Jersey (n = 72)

Category	Percent of Sample
Gender	74.1 % male
non responses	16.6 % of sample
Annual Household Income	
< $25,000	1.8 %
$25,001 - $50,000	20.4
$50,001 - $75,000	27.8
$75,001 - $100,000	12.9
> $100,000	12.9
non respondents	24.0
Respondent Uses Transit	
Often	79.6 %
Occasionally	9.3
Never	7.4
non respondents	3.7
Average number of transfers required for commute if transit is used	2.5 transfers/one way trip
Average Transit cost when commute is made by transit.	$4.15/ one way trip
Average length of trip from home to bus stop	12 minutes

TABLE 2 Multinomial Logit Equation for Commuting Choice Decisions Made by Employees of Technical Center of Port Authority of New York and New Jersey, Spring 1993

Attribute	Logit Coefficient	t score
Public Transit Equation		
Household Income	-0.000011	5.3
Commuter Often Takes Transit	0.86	3.7
Commuter Never Takes Transit	-1.29	3.1
Commuter normally walks to transit stop	0.61	4.1
Time taken to get to bus or train stop	-0.021	3.9
Transit Subsidy	0.32	5.8
Carpool Equation		
Mode specific constant	-1.58	3.3
Time saved carpooling in comparison to transit	0.032	5.4
Number of transfers needed to complete transit trip to work	0.64	7.5
Drive alone travel time to work	-0.027	4.9
Vanpool Equation		
Mode specific constant	-0.91	2.1
Commuter is female	0.86	3.4
Time saved vanpooling in comparison to transit	0.027	2.1
Vanpool subsidy ($)	0.38	6.6
Number of transfers used for transit based trip to work	0.29	4.2
Initial Likelihood	-1103	
Final Likelihood	-877	
Rho bar squared	.20	

estimation. The use of the computed standard error assumed that each observation is independently distributed. It is recognized that this is less strict than the assumption that only the individuals providing data are independently distributed (*10*).

Most of the employees taking the survey are public transit users; therefore, their knowledge of commuting conditions should be strongest for the public transit alternative. The attributes that combine to generate the implicit value of utility are shown in the public transit equation. Six variables have been retained in the final estimation of this equation. The single socioeconomic variable that enters the equation is annual household income. The negative sign indicates that employees increase their valuation of public transit as their incomes decrease. Four variables reflect the impact of respondents' current commuting conditions on their valuation of public transit. Commuters who often take transit have a positive valuation for the future use of transit; alternatively, those commuters who never take transit have a strong negative valuation. Three alternative ways of getting to the future transit stop were presented to respondents: walk, drive to a park-and-ride lot, or have someone drop the respondent off at the station. The reference category is: have someone drop the respondent off at the station. The utility equation shows that the ability to walk to the station generates a positive marginal utility relative to the reference category. The final argument entered into the public transit equation is the value of a transit pass used as a qualified fringe benefit under the U.S. Energy Act of 1992. The transit subsidy is shown to be valued positively by the respondents.

The second utility equation is estimated for the carpool commuting option. Three variables and an alternative specific constant are retained in the equation. Respondents, currently transit or carpool commuters, show that a time savings will increase the desirability of carpooling relative to the other alternatives. The second variable shows that the number of transfers needed to complete the public transit journey acts to reduce the demand for transit and increases the desirability of carpooling. Finally, it shows that long driving times tend to reduce the desirability of carpools. It should be noted that socioeconomic variables such as gender and income were tested for entry into the carpooling equation. In no case were statistically significant coefficients recovered from the sample.

The final utility equation shows the attributes that produce significant coefficients for the vanpool option. Four variables were retained for the final model. In addition to the mode-specific constant, female respondents show a strong desire to use the vanpool option. As with carpooling, respondents increase their valuation of vanpooling as the number of transfers that they are forced to make when using public transit increases. Last, the existence of a vanpool subsidy program is positively related to the utility derived from vanpooling to work.

TRADE-OFF ANALYSIS

The ratio of marginal utility values shows the rate at which commuters trade off attributes either within an alternative or across alternatives. Table 3 gives seven marginal rates of substitution for the value of the transit subsidy and five other attributes taken from either the carpool or the vanpool alternatives. The values show the magnitude of the change in an attribute needed to offset a unit change in another attribute while keeping the commuters at the same level of utility or satisfaction with their commuting services as before the change.

The first value shows the level of a subsidy to vanpools that is equivalent to a \$1.00 subsidy to transit users. The model shows that the subsidy to transit users must be \$1.00 for each \$0.83 subsidy given to vanpoolers for utility levels to remain unchanged. That is, where transit ridership is to remain stable, for each \$0.83 subsidy per trip given to vanpoolers, a \$1.00 subsidy must be given to transit users.

Similarly, as the tasks essential to mounting effective rideshare matching programs are understood, transportation coordinators will be increasingly able to identify successful matches. In part, this effort will shorten the total time required to rideshare. The MRS shows that for either commuting alternative, each minute of journey time that is reduced by a commuting alternative relative to transit will require an approximately 10-cent increase in the transit subsidy for utility to be left unchanged.

TABLE 3 MRSs for Attributes of Public Transit Use Compared with Attributes of Car- or Vanpool

Attribute	MRS
MRS between vanpool subsidy and a \$1.00 transit subsidy	\$0.83 vanpool/\$1.00 transit
MRS between transit subsidy and a 1 minute commute time savings by carpool	\$0.10 transit subsidy/1 min. saved
MRS between transit subsidy and a 1 minute commute time savings by vanpool	\$0.09 transit subsidy/1 min. saved
MRS between a transfer and the transit subsidy (carpool users)	\$2.02/transfer
MRS between a transfer and the transit subsidy (vanpool users)	\$0.91/transfer
MRS between the necessity to transfer and additional time spent on public transit (carpool users)	19.7 minutes/transfer
MRS between the necessity to transfer and additional time spent on public transit (vanpool users)	10.5 minutes/transfer

The final trade-offs to be examined relate the value of the transit subsidy to the number of transfers required by commuters in their journeys to work. The MRS provides an estimate of the transfer penalty. Early work by Horowitz and Zlosel (*11*) show that satisfaction with a bus trip declines significantly with the introduction of a transfer. Han (*12*) shows that without capacity constraints, bus systems will suffer a loss of ridership with the introduction of transfers.

The transfer penalty differs in value depending on the alternative to which a trip with transit is being compared. Table 3 provides two measures of the transfer penalty: a money cost and time lost equivalent value. Where the alternative mode is the carpool, a transfer is valued at \$2.02. That is, when one additional transfer is required, the transit subsidy required to maintain the commuter at an equal level of utility is \$2.02; in contrast, the vanpool user values the transfer at \$0.91. Measurement of the transfer penalty in terms of time lost compares the marginal utility of a transfer with that of time saved using one of the rideshare alternatives. Where the alternative is carpooling, the transfer penalty is valued as an additional 19.7 min spent on transit; where the alternative is vanpooling, the transfer penalty is equivalent to an additional 10.5 min spent on transit.

MODAL SPLIT

The advent of a subsidy program incorporating both transit and vanpool modes combined with the requirements of the Clean Air Act suggests that significant mode shifts may occur soon. Table 4 presents the results derived from the use of the logit model for forecasting purposes. The forecasts are derived using the probabilistic approach (*13*). In this approach, the market share for each mode is calculated as the weighted average of each individual's mode-specific probabilities. This technique has a tendency to overestimate the mode share probabilities for minor modes when compared with the strictly deterministic technique. The socioeconomic and demographic data used to estimate the logit parameters are now used to fix the policy forecasts to the employees of the site being studied.

The first scenario describes a situation similar to the current conditions surrounding the commute to work. The employees who have taken advantage of the \$3.00/day transit subsidy are assigned that value, the others are assigned a subsidy of \$0.00. The difference between car- and vanpool commuting times and that for public transit are assigned values on the basis of current perceptions

TABLE 4 Projected Modal Split for Employees Who Currently Take Transit and Carpool to Work

Scenario	Transit Subsidy \$	Carpool shorter than Transit (min.)	Vanpool shorter than Transit (min.)	Vanpool Subsidy \$	Percent Transit %	Percent Vanpool %
1	3*	10	-30	0	74.8	8.9
2	3	10	-30	0	79.7	7.1
3	3	20	0	0	71.4	13.6
4	3	30	10	0	66.1	16.1
5	3	30	10	1	61.8	21.7
6	3	30	10	2	56.7	28.4
7	3	30	10	3	50.6	36.2

by employees received in focus groups. On average, employees believe that carpooling will save them 10 min/trip and that vanpooling will add an additional 30 min. The reason for the high time cost applied to vanpools reflects the current high information costs associated with vanpool formation. The employee transportation coordinator's role in future programs will be to reduce this cost significantly by establishing and maintaining rideshare groups. Last, reflecting the current situation, the vanpool subsidy is set equal to 0. The result of this scenario finds 75 percent of the employees choosing transit, 16 percent choosing carpools, and 9 percent vanpools. The actual mode split under the baseline commuting conditions is 81 percent transit and 19 percent carpool.

Scenarios 2, 3, and 4 were constructed to determine the effect of an active or effective transportation coordinator on mode split. Scenario 2 shows the influence of a fully used \$3.00 transit subsidy with all other policy variables set at their baseline values. The result is the rise in transit use to 79 percent of the employees. Scenarios 3 and 4 improve the information regarding ridesharing opportunities among employees of the site. In the first case, it is projected that the transportation coordinator will improve the carpool over transit time difference by 20 min, and they will bring vanpool travel times even with transit. The results show a significant rise in both forms of ridesharing.

The last three scenarios introduce a variable vanpool subsidy ranging from \$1.00 to \$3.00/day. The subsidy offsets the daily cost of \$3.00 needed to reserve a place on the van. As was noted in the text, this is a relatively low value given the cost structure for leasing and operating a van and the tendency for employees to exit vanpools as a result of job or residential shifts. Scenario 5 displays the results of a \$1.00/day tax-free vanpool subsidy combined with the transit subsidies and time differentials shown in Scenario 4. The \$1.00 vanpool subsidy increases the vanpool share from 16 percent to just under 22 percent; the new vanpool riders are drawn mostly from existing transit riders. Scenario 6 shows the result of a \$2.00 vanpool subsidy program; here the vanpool market share increases to 28 percent. The final scenario presents employees with the maximum tax-free subsidy of \$3.00/day; the model shows that public transit usage declines to 50.6 percent while vanpools rise to 36 percent of the commuting trips.

The effective impact of the employee subsidy program must be reexamined in light of the cost structure for vanpool operation as well as the effectiveness of the transportation coordination program at an employment site. Assuming that a van operates 20 days a month, travels 100 mi/day, has a gas mileage of 8 mi/gal, and that gas costs \$1.30/gal, the monthly cost of operating such a van is approximately \$900 for leasing and insurance plus \$350 for gas, oil, and service, for a total of \$1,250. A 16-passenger van operating at capacity and charging \$3/trip will generate a monthly revenue of \$960; at \$4/trip the revenue generated will be \$1,280. When ridership declines to 10 passengers, the monthly revenue becomes \$800 and an employer subsidy of \$450/month will be needed to keep employees in the vanpool. Therefore, in order to maintain this level of vanpool operation, the employer must offer each employee the qualified transportation fringe at \$3.00/day and an additional subsidy of \$2.25/rider to the van leasing firm. Without the firm's willingness to support the lease directly, the \$3.00 transportation fringe benefit will be effectively cut to \$0.75/day. The consequences of the fringe benefit level, taken from the National Energy Act, and an effective transportation coordination program implemented at each employee site, brought about through the Clean Air Act, will result in a decline in ridership ranging from between 15 and 25 percent of the site's current transit ridership.

CONCLUSIONS

The demand for public transit in urban areas is in part defined by a set of captive riders. The gas crisis of the middle to late 1970s stimulated corporate sponsorship of car- and vanpools; with the increase in gasoline stocks during the 1980s, support for ridesharing waned. Suburban commuters returned to the single-occupant vehicles; urban commuters, depending on their economic conditions and urban locations, again became captive to their automobiles or to public transit. The decade of the 1990s presents a new set of challenges to the survival of urban public transit. The combined influence of the Clean Air Act of 1990 and the Energy Act of 1992 may stimulate the demand for public transit by shifting drivers out of single-occupant vehicles and into transit. However, the research presented in this paper shows that along with a shift to transit there could be a significant decay in ridership coming from current transit users. To the extent that there is a conscious policy supporting public mass transportation, efforts should be made to either stabilize or enhance transit ridership. It is clear from this research that demand suffers as the number of transfers increase and as the time required to get from home to the public transit stop increases. Any decline in ridership will undoubtedly increase headways and in turn lead to further declines in ridership. This suggests that a differential be established in the subsidy given to transit versus that given to vanpool users.

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Reducing Drive-Alone Rates at Small Employer Sites: Costs and Benefits of Local Trip Reduction Ordinances—Pasadena Towers Case Study

JACQUELINE STEWART

In July 1986 the city of Pasadena, California, adopted a trip reduction ordinance (TRO) that recognized that any new development in the city would generate travel and parking demands that could harm traffic flow and parking in surrounding areas. The experience of one Pasadena developer is evaluated; this developer, in compliance with the TRO, was faced with designing, implementing, and operating a building-based transportation demand management (TDM) program. Vehicle trip data generated by workers at Pasadena Towers are compared with vehicle trip data generated by workers at a neighboring control site. The costs and non-trip-related benefits of the Towers' building-based TDM program are also discussed. The ratio of employees arriving at the work site to the number of vehicles (average vehicle ridership, or AVR) was found to be the same for the control site as it was for Pasadena Towers. This was contrary to expectations and indicates that the transportation program offered by Pasadena Towers did not appear to reduce vehicle trips beyond a base level existing at a similar building with no TDM program. In terms of AVR alone, therefore, the trip reduction program did not appear to be effective. Attitudinal survey results, however, report that 51 percent of Pasadena Tower's employees who rideshare were encouraged to do so by the TDM program. The percentage of employees who use alternative modes to travel to work at Pasadena Towers is also higher than at the control site, suggesting that the program is encouraging workers to rideshare but that the modes they are using do not have as great an impact on AVR as those used by workers at the control site.

In compliance with federal and state Clean Air Acts, the South Coast Air Quality Management District (SCAQMD) introduced an Air Quality Management Plan in 1991 and a Carbon Monoxide Attainment Plan (CO Plan) in 1992. These plans require local governments to adopt and implement trip reduction ordinances (TROs) and growth management initiatives designed to reduce emissions from mobile sources. These requirements go beyond those of Regulation XV, which applies only to employers in the South Coast Air Basin who employ more than 100 employees at any one work site. Although the plan requirements have not yet been enacted into law, they will require local governments to implement trip reduction strategies.

Once the plan requirements are enacted, the SCAQMD will be charged with monitoring the progress of local governments toward their respective goals. If the SCAQMD deems compliance to be insufficient to achieve the established emission reduction goals, it will be required to introduce a regional rule from which jurisdictions making progress toward, or attaining, their targets will be exempt.

In addition to impending requirements from the SCAQMD, Phase 1 of the transportation demand management (TDM) element of the California state-mandated congestion management plan currently requires cities in nonattainment areas to introduce TROs that include requirements for developers to incorporate TDM elements, such as preferential parking, into the design of new buildings. Phase 2, when adopted, will require cities to include in their TROs a wider range of TDM measures. The experience of cities that have already adopted TROs is thus of great interest to cities that are currently required, or may be in the future, to adopt and implement them.

PURPOSE

This study analyzes the impact of a local TRO on trip reduction by comparing employee vehicle trip data generated by workers in two Pasadena office and retail developments. The test building, in compliance with Pasadena's TRO, has TDM elements incorporated into its design, development, and operation. The control building was constructed before the introduction of the TRO and has no TDM elements incorporated into its design and operation. The costs and non-trip-related benefits of the building-based TDM program are also discussed.

It is hoped that this study will (a) help other local governments and developers faced with writing and following TROs to determine the likely impacts in terms of costs and benefits of local TROs; and (b) help regulatory, rideshare, and other agencies determine if building-based TDM programs are appropriate and effective strategies for reducing commute trips among employers with fewer than 100 employees. Although credits will be given only for trips reduced over and above those attributable to Regulation XV, the determination of appropriate and effective strategies for reducing commute trips in the small employer market will become important if the Regulation XV threshold is reduced to include employers with fewer than 100 employees.

PASADENA'S TRO

In July 1986, with no legal requirement, the city of Pasadena, California, adopted an ordinance that established Trip Reduction Standards in Specified Developments. Ordinance 6172 was de-

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signed to reduce the peak-period demand on existing infrastructure by encouraging the use of alternative work schedules and transportation modes other than the single-occupancy vehicle.

Pasadena Towers is a 465,000-ft^2 mixed-use development located in Pasadena's downtown at the southwest corner of the intersection of Lake Avenue and Colorado Boulevard. Phase 1 was completed in 1990 and consists of a nine-story office tower, two subterranean and five aboveground levels of a parking structure, a cafeteria, and a small coffee shop. Phase 2 was completed in 1992 and consists of a second nine-story office tower and a standalone two-story building. Some street-level retail spaces have also been incorporated into the development.

The Pasadena TRO requires that all new major developments (those that will employ more than 500 employees) submit a plan for a TDM program. The ordinance does not set minimum standards for the program but suggests elements that the program might include. To comply with the ordinance, the developers of Pasadena Towers submitted a TDM plan to the city. The program includes an extensive list of TDM elements including, but not limited to, the following: a full-time employee transportation coordinator (ETC) with an office in the lobby of Tower One, ridematching assistance, bus pass discounts and on-site bus pass sales, a guaranteed-ride-home (GRH) program, reduced carpool parking rates for tenants, and cash incentives for walkers and bicyclists.

Parking Requirements

The parking spaces required to meet city codes were incorporated into the development's design, but as tenants began to occupy the building, the parking requirement increased from 1,262 spaces to 1,460, leaving a shortfall of 198 spaces. In order for a conditional use permit to be granted by the city, the developers, unable to build more spaces, were faced with a choice: provide tenants with off-site parking and make a number of spaces tandem, or reduce the demand for those spaces.

The developers, eager not to harm the desirability of their development by providing off-site or tandem parking, chose to reduce the demand for parking. Demand for 71 spaces was eliminated via shared parking arrangements. Demand for the remaining 127 parking spaces was eliminated via the introduction of an "enhanced" TDM program. There is currently, however, no shortage of parking in the development, but all the space is not yet leased.

Enhanced TDM Program

In recognition of the financial commitment involved in offering and implementing a TDM program, the ordinance provides for developers to reduce their parking requirements by up to 8 percent by providing a full-time on-site ETC. A further reduction of up to 11 percent is also possible if a TDM plan is approved by the city traffic and transportation engineer. The plan must describe the program in detail and estimate the number of trips that the program will reduce and the number of parking spaces for which demand is expected to be eliminated.

To reduce the demand for the remaining 127 spaces (8.7 percent of the code requirement) the developers submitted an enhanced TDM plan to the city. The incentives proposed in the enhanced plan were not extensive, but they did not need to be because the developers already had in place many more TDM elements than required by the ordinance.

PROGRAM COSTS

The budget for the Pasadena Towers transportation program in 1993 is estimated to be $92,000. The total cost is expected to be divided among different program components in the following way:

Component	*Cost ($)*
ETC salary	35,000 (estimated)
Incentives	50,000 (based on past experience)
TMA membership	5,000 (includes GRH program and information resources)
Rideshare fair	2,000
Total	92,000

Who Pays?

The cost of running the transportation program is considered to be an operating cost. Tenants pay for the program in the same way that they pay for utilities: the costs are divided among the tenants on the basis of the area of the space that they lease. The owners pick up the tab for space that is not yet leased. This strategy means that tenants pay a fixed sum regardless of how many of their employees participate in the program. Thus, it is in the interest of individual tenants to encourage as many employees as possible to participate, since the cost of each additional participant will be divided among all the tenants and is not borne solely by the individual tenant.

How Much Do They Pay?

The cost of operating the Pasadena Towers transportation program in 1993 is expected to be $92,000. The total square footage of the development is 465,000 of which 338,000 (72 percent) are currently leased. The cost of the program to the tenants is approximately $0.20/ft^2. The existing tenants, therefore, are currently paying for 72 percent of the program ($66,240). These tenants currently employ approximately 950 employees, which means that, on average, they are paying $70/employee/year. The cost per employee, however, is higher because the owners are footing the bill for 28 percent of the total cost (that portion of the total space that is not yet leased). The actual cost per employee is $97/year.

Cost Comparisons

A study of 37 Regulation XV transportation programs, completed by Commuter Transportation Systems (CTS) in April 1992, found the average annual cost per employee to be $70. A study of 1,095 Regulation XV transportation programs, completed by Ernst and Young for SCAQMD in August 1992, found the average annual cost per employee to be $81. These figures indicate that Pasadena Towers' per-employee cost is higher than the averages found by CTS and Ernst and Young, but the Towers' program offers more incentives than the average Regulation XV work site. The tenants, however, are actually paying the same as the average found in the CTS study and less than the average found in the Ernst and Young study. However, as the remaining space is leased, the number of employees will increase and the cost per employee should decrease as fixed costs are spread over more employees.

BENEFITS

The benefits of the transportation program can be divided into three broad categories: benefits to the developer, benefits to the tenants and employees, and benefits to the city and the environment.

Benefits to Developer

Benefits to the developer include the following:

- A reduction in parking requirements: in this case the developers, faced with a parking shortfall, were able to avoid the cost and potential inconvenience to tenants of providing tandem or off-site parking. In other cases developers may have the opportunity to save money by actually constructing fewer parking spaces than city codes require. The average national construction cost of an aboveground parking space in 1988–1989, excluding land costs, was estimated to be between $7,000 and $9,000 (*1*).

In this example, if the developer had built the 127 spaces required by the city, the cost might have been between $889,000 and $1,143,000. However, this is a hypothetical cost since the demand for the additional spaces would have been met not via new construction but by tandem parking arrangements or by leasing off-site parking spaces—a solution that would have been much less costly. In any case, the costs of additional construction or of leasing off-site parking is passed on to the consumer (the tenant) in the form of higher leases and operating costs and is not borne solely by the developer. It is in the developer's interest, however, to minimize costs and pass on at least a portion of those savings to the consumer in the form of lower lease and operating costs.

- The program is an added service provided by the building for its tenants that serves to increase the ''attractiveness'' of the development to potential tenants. For employers with more than 100 employees, the program has the added advantage of reducing many or all of the administrative and organizational duties associated with the legal obligation of complying with Regulation XV.

Benefits to Tenants and Employees

Benefits to tenants and employees include the following:

- Reduced cost and time spent introducing and implementing a transportation program for employers affected by Regulation XV and those who may be affected in the future (i.e., employer sites with 50 to 100 employees).
- Expanded benefit package for tenants to offer employees with little or no administration.
- Economies of scale: if individual tenants were to offer similar programs to their employees, the cost would probably be greater than when provided communally. This has potential positive ramifications if Regulation XV is extended to employers with fewer than 100 employees or if small employers are required to comply with other local trip reduction strategies.
- Direct financial benefit to employees.

Benefits to City and Environment

Benefits to the city and the environment include the following:

- A reduction in social costs, which are environmental costs that are generated by an individual or group of individuals but borne by society as a whole. In the case of new development, the developer reaps financial reward while society pays for the congestion and pollution generated. The introduction of TROs by local governments can, therefore, be seen as a recognition of social costs and an effort to return some of those costs to the developer. In this case, the city of Pasadena is asking developers to take responsibility and pay for measures that will reduce some of the social costs they generate.
- A fundamental benefit of a building-based trip reduction program is that it purports, as the name implies, to reduce trips. A reduction in vehicle trips in turn has a beneficial impact on levels of congestion and pollution, which benefits society as a whole. A local jurisdiction implementing a building-based TRP also benefits by fulfilling, at least in part, their new legal requirement to meet predetermined trip reduction goals.

The primary purpose of this study is to determine the impact of the Pasadena Towers TDM program in an effort to determine the cost-effectiveness of a building-based trip reduction plan (TRP) introduced as a direct result of a TRO. The methodology used to determine the impact of the Pasadena Towers program and the results found are outlined in the following sections.

IMPACT ON TRIP REDUCTION

The impact of a trip reduction strategy is usually measured by comparing trip data recorded before program implementation with corresponding trip data recorded after program implementation; the impact is deemed to be the difference between the pre- and the post-program results. In this case the trip reduction program has been in operation since the building was opened, and no baseline trip data are available. Fortunately, a similar development with similar tenants, and with no TDM program, is available to serve as a control site.

Two North Lake is a 207,000-ft^2 office and minor retail development located catercornered to Pasadena Towers on the northeast corner of Lake Avenue and Colorado Boulevard. Two North Lake houses approximately 550 employees, 420 of whom work for companies with fewer than 100 employees. This building was constructed before the introduction of the Pasadena TRO, and the developer was under no obligation provide tenants with a trip reduction program.

CTS approached the management at Two North Lake in October 1992 to solicit their cooperation to serve as a control group by allowing CTS to survey their tenants to obtain baseline trip data. Management agreed to participate in the study. However, they had little time to devote to the project and, faced with many more pressing obligatory requirements, were not able to distribute the survey until April 1993.

This illustrates one of the difficulties in using controls to measure the impact of trip reduction strategies: often control sites are under no legal obligation to participate in studies and have little or no incentive to devote the necessary time and resources. Despite these difficulties, however, cooperation was secured and an average vehicle ridership (AVR) survey was distributed to the 380 employees in Two North Lake who work for employers with fewer than 100 employees and who are offered no employer or building-based incentives to adopt alternative transportation modes; 192 surveys were returned, a response rate of 50 percent. This response rate is extremely high, considering that the building owners, management, tenants, and employees are not legally required to survey their employees for commute trip data. An AVR survey was also distributed to the 268 employees at Pasadena Towers who work for employers with fewer than 100 employees and who are offered building-based incentives to adopt alternative travel modes; 179 surveys were returned, a response rate of 67 percent.

Assumptions Made in AVR Calculation

It is assumed that the employees not returning completed surveys use alternative travel modes in the same ratio as those returning surveys. This assumption is contrary to the SCAQMD's methodology for calculating AVR for Regulation XV employers. In SCAQMD AVR calculations, nonrespondents are treated as drive alones regardless of how they actually travel to work; such treatment of nonrespondents has the effect of lowering AVR. This methodology is designed to encourage regulated employers to get as high of a response rate as possible and is also underlain with the belief that users of alternative travel modes are more likely to return surveys than drive alones.

In this study it was decided that since employers in Two North Lake are under no legal obligation to have their employees complete AVR surveys, there should be no penalty for nonrespondents. It is also assumed that since the employees at Two North Lake are not familiar with AVR calculations and were given a financial incentive in the form of a prize drawing to complete and return the surveys, drive alones were just as likely to return surveys as users of alternative modes. To make the comparison between Pasadena Towers and Two North Lake, Pasadena Towers' AVR calculation was treated in the same way: nonrespondents were not counted as drive alones.

Employee Occupations

In Pasadena Towers, 63 percent of respondents work in banking, investment, and finance; 12 percent work in law; 18 percent in insurance; and 7 percent in "other." In Two North Lake, 52 percent of respondents work in banking, investment, and finance; 10 percent work in law and medicine; 33 percent in insurance; and 5 percent in "other."

AVR Results

Two North Lake

The average AVR for the 19 companies is 1.14, with a range from 1.00 to 2.00. The average one-way commute distance for the 192 respondents is 18 mi; 68 percent of respondents indicated that their work hours are regular, and 31 percent indicated that their work hours vary from day to day.

Pasadena Towers

The average AVR for the 11 companies is 1.14, with a range from 1.00 to 1.40. The average one-way commute distance for the 179 respondents is 11 mi; 47 percent of respondents indicated that their work hours are regular, and 46 percent indicated that their work hours vary.

What Do These AVR Results Mean?

The AVR for the control group (Two North Lake) is the same as the AVR for the test group (Pasadena Towers). Using the SCAQMD's methodology, however, the AVR for Pasadena Towers would have been higher due to the lower nonresponse rate; but, as noted, an AVR calculation based on actual responses was judged the most appropriate.

These results indicate that the transportation program offered at Pasadena Towers did not seem to reduce vehicle trips among employees working for small employers. On average, as many trips per employee were made by Towers' workers as by Two North Lake workers. The sample, however, is small, and the behavior of a few individuals can have a dramatic effect on the overall AVR result.

Analysis of travel behavior at the two sites shows that the drive-alone rate is lower at Pasadena Towers (77.9 percent) than at Two North Lake (83.3 percent). This means that a larger percentage of employees use alternatives to driving alone at Pasadena Towers than at Two North Lake. The carpooling rate is also higher at Pasadena Towers (19.8 percent) than at Two North Lake (10.3 percent). This may suggest that employees who might otherwise have ridden the bus to work are being encouraged to carpool; this, in turn, assumes that overall the carpool incentive "package" is more attractive than riding the bus. The fact that the two sites have the same AVR is based on the larger percentage of Two North Lake employees who ride the bus to work (4.1 percent compared with 0.9 percent). Employees riding the bus have a greater relative impact on AVR than carpooling, for example, because more vehicles trips are eliminated.

Workers at Pasadena Towers are also more likely to have schedules that vary from day to day (47 percent) compared with workers at Two North Lake (31 percent). Varying schedules can make it harder for people to commute by carpool and vanpool and also to ride the bus if the schedule is limited.

Pasadena Towers: Attitudinal Survey Results

In addition to an AVR survey, an attitudinal survey was distributed to employees at Pasadena Towers to gain additional insight into the effect of the program. Employee attitudes toward the program are extremely positive, and awareness of the program extremely high. The highlighted results of the attitudinal survey are given here:

- 51 percent of ridesharers indicated that the incentives and information provided by Pasadena Towers influenced their decision to rideshare.

- 84 percent of respondents indicated that they were aware that incentives were offered to encourage them not to drive alone. Those who were already ridesharing, however, were more aware (93 percent) than those who always drive alone (81 percent). Awareness overall, however, is extremely high.
- 84 percent of respondents indicated that they were aware that a rideshare fair was held at the site in September 1992, the level of awareness was the same for ridesharers as it was for drive alones. A larger percentage of ridesharers (89 percent) attended the rideshare fair than drive alones (51 percent), although attendance was still very high for drive alones.
- 75 percent of respondents indicated that they were aware that an ETC was available on-site to help them find an alternative to driving alone everyday. Again, ridesharers were more aware of the ETC's existence (88 percent) than drive alones (71 percent).
- Only 42 percent of respondents indicated that they aware a GRH could be provided in the event of an emergency. Again, the level of awareness was higher among ridesharers (55 percent) than among drive alones (38 percent).
- 50 percent of drive alones indicated that one of the main reasons they did not rideshare was the need for their car before or after work. The need for a car during the day for company or personal business was also stated as a reason for not ridesharing by more than 20 percent of employees.
- 46 percent of drive alones indicated that an irregular schedule was one of the main reasons that they did not rideshare. This is consistent with the 46 percent of respondents who indicated on their AVR surveys that their hours varied.
- Only 4 percent of drive alones were not aware of their other travel options and only 13 percent indicated that they did not have anyone to share the ride with.

In sum, these results indicate that it is probably not a lack of awareness that is limiting higher participation but varying work schedules and lifestyles. Half of respondents who always drive alone indicated that the main reason that they did not rideshare was because they needed their car before or after work. Forty-six percent said an irregular schedule was a reason for their not ridesharing.

Are Building-Based TRPs Effective?

It would seem that, in this case, the Pasadena Towers TRP did not seem to be effective in terms of encouraging employees of small employers to reduce more vehicle trips than similar employees working in a neighboring building with no TRP. Although it must be remembered that the sample is small and that the test site was compared to a control site and not to itself before implementation. Presurveys, however, are not possible in the case of building-based projects since programs go into operation as soon as tenants occupy the buildings

Pasadena Towers is also home to three employers that, by virtue of their size, are obligated to comply with Regulation XV. All three employers use the building-based TDM program as the basis for their Regulation XV TRP, but one offers no additional incentives. There are 140 employees working for this employer, and their SCAQMD-approved AVR, calculated at the same time as the small employers', was 1.30. This appears to indicate that the transportation program alone is not solely responsible for AVR, and that small employers are likely to have lower AVRs than larger companies even when offered the same incentives. This phenomenon may be because employees at smaller sites have a smaller base of potential carpoolers, for example, to choose from. Thus, although there is a large pool of potential ridesharers at the site, some people may be less willing to sign up or less willing to carpool with someone that they do not know. The individual AVRs for the 11 employers in Pasadena Towers appear to show that this may be the case; for example, the seven smallest companies (all fewer than 20 employees) have five of the lowest AVRs.

The fact also remains that the small employers at Pasadena Towers are not held individually accountable for encouraging their employees to rideshare in the same way as Regulation XV employers are. This may translate into a lack of encouragement to their employees or even a lack of understanding if an employee has to leave on time to catch a bus, carpool, or vanpool, which will have a detrimental effect on ridesharing behavior.

This study is also a snapshot in time that does not consider what the future will bring; for example, it is likely that in the future, the continued support of the Pasadena Towers ETC and the building management company will encourage greater participation. In contrast, the AVR at Two North Lake arose essentially by chance and is, therefore, probably not likely to change much in the future.

It must also be remembered that no matter how carefully a control site is chosen, it cannot exactly replicate a test site. It is hoped, however, that this study raises some issues and lays the groundwork for future studies.

What Can Others Learn?

The most important thing for other cities, building owners and managers, and regulators to learn from this study is that for building-based trip reduction programs (and local TROs) to be effective, there may need to be some legislation that hold individual employers accountable. However, before this step is taken, more work needs to be done to determine just what is effective and what is a reasonable AVR target for small employers. More studies need to be undertaken which attempt to establish a base level from which progress can be measured. The 1.14 average AVR for the 11 companies in Pasadena Towers may, in fact, be a good ratio of vehicle trips to employees considering the type and the size of the employers—or it may not.

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Evaluating the Cost-Effectiveness of Employer-Based Trip Reduction Programs: Reviewed and Reexamined

JACQUELINE STEWART

Crucial to the outcome of transportation demand management cost-effectiveness studies is the ability to identify both cost and effect. Unfortunately, neither element is easily identified in practice, and a definitive methodology for determining cost-effectiveness has yet to be developed. To date, three major studies have attempted to determine the cost-effectiveness of employer-based trip reduction programs using such measures as cost per employee and cost per one-way trip reduced. Each study, however, uses slightly different methodologies and assumptions and, as a consequence, arrives at different, noncomparable results. Before embarking on major new cost-effectiveness studies, it is necessary that researchers clearly understand the methodologies used in existing studies. The methodologies and results of cost-effectiveness studies by Comsis Corporation, Commuter Transportation Services, and Ernst and Young are outlined. The problems inherent in such studies are also discussed.

Throughout the United States, local and regional governments are adopting trip reduction regulations that require cities, employers, building owners, and developers to implement transportation demand management (TDM) programs aimed at reducing commute trips. TDM strategies are designed to improve the efficiency with which the existing transportation infrastructure is used by encouraging the use of high-occupancy transportation modes and alternative work schedules.

As regulating agencies increase the pressure to meet their trip reduction goals, they, in turn, are called on to demonstrate the cost-effectiveness of the strategies that they promote and enforce. As a result, recent months have seen the release of two major requests for proposals. At the federal level, TRB is sponsoring research designed to develop a procedure "to better evaluate the benefits, costs, and possible productivity gains resulting from employer-based TDM strategies; and, to provide guidance to public agencies on the system-wide costs, benefits, and other impacts necessary to stimulate and support further implementation of TDM strategies" (*1*). In the Los Angeles region, the South Coast Air Quality Management District (SCAQMD) is funding research which hopes to determine "the true cost-effectiveness of Rule 1501 (formerly Regulation XV)" (*2*).

To date, a number of studies have attempted to determine the cost-effectiveness of employer-based TDM programs. Three major studies include Comsis Corporation's work on the *Cost Effectiveness of Travel Demand Management Programs* (*3,4*), Ernst and Young's *Regulation XV Cost Survey* (*5*), and Commuter Transportation Services's (CTS) *What Price Success? Regulation XV Trip Reduction Plans: Investment Patterns and Cost Effectiveness* (*6*). Although Comsis's work is based on TDM case studies from around the country, Ernst and Young and CTS focus on employers complying with Regulation XV. Both Ernst and Young and CTS use SCAQMD's data base as a measure of effectiveness against which to analyze cost data.

Crucial to the successful outcome of such studies is the ability to identify and quantify both cost and effect. Unfortunately, however, neither element is easily identified, and a definitive methodology for determining cost-effectiveness has yet to be developed. Each of these studies use different measures, methodologies, and assumptions and, as a consequence, arrive at different, noncomparable results. Thus, while the industry waits for answers, there is a need to review the work conducted so far.

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PURPOSE

This paper outlines the methodologies and results of the three studies and outlines the problems inherent in such studies.

COMSIS CORPORATION

Evaluation of Travel Demand Management Measures To Relieve Congestion

In 1989 Comsis Corporation prepared for FHWA a study on the effectiveness of employer-based TDM measures in relieving traffic congestion. The study reviewed the experiences of 11 TDM case study programs from across the nation (*3*).

Methodology

To determine the net impact of each TDM program, the following standards were used: if possible, the program was compared with the situation before program implementation; in cases where such a comparison was not possible, the program was compared with regional averages; in some cases, instead of (or in addition to) regional comparisons, the program was compared with a control site.

The net-change attributable to TDM was expressed as the percentage reduction in one-way vehicle trips. A vehicle trip rate (i.e., 71 vehicles per 100 travelers) was calculated for each site and compared with a control site. The percentage change in the vehicle trip rate was used to represent the effect of the effect of the TDM program. For example, Company A's employees used 71 vehicles per 100 travelers whereas its control group used 86.4 per 100.

Thus the percentage reduction in vehicles in the TDM program at Company A generated was 17.8 percent ([86.4 − 71.0]/86.4). Since there are 1,000 employees at Company A, it is assumed that 178 vehicles were reduced by the TDM program (1,000 × 17.8%). However, since each employee vehicle generates a trip to and from work, the TDM program at Company A can be said to have reduced 356 vehicle one-way trips per day, 265 workdays a year.

Percentage vehicle–trip reduction estimates for the 11 cases ranged from 5.5 to a 47.6 percent, with a weighted average reduction of 20 percent. This study, however, considered only the impact of TDM and not the cost.

Cost Effectiveness of TDM Programs

In 1990 Comsis was commissioned by the Maryland–National Capital Parks and Planning Commission to extend the FHWA study to include an analysis of the cost of TDM programs. Ten of the FHWA cases were included in the cost-effectiveness study along with 2 additional cases, and 10 additional cases were added later to make a total of 22 (*4*).

Comsis's objectives were to (a) determine the total cost to operate a TDM program, (b) distinguish between direct and indirect costs and savings, and (c) determine the net cost per trip reduced. In cases where employers were unable or unwilling to supply all the information for a complete analysis, either a particular cost item was left blank or approximations were made using indirect data.

Results

The results from the 22 cases were summarized and presented at a 1-day "Implementing TDM Programs" seminar sponsored by the U.S. Department of Transportation, FHWA, FTA, and ITE in April 1993 (*7*). For each of the 22 employer-based programs, the percentage change in trip reduction, costs/savings per one-way trip, and daily net cost per employee was calculated.

The vehicle trip reduction rate for the sample ranged from a high of 47.9 percent to a low of 3.7 percent, with an average of 23 percent. In only 7 of the 22 cases, however, was the post-program trip reduction rate compared with the presituation at the same site. For these seven cases the trip reduction rate ranged from 26.1 to 3.7 percent, with an average of 14 percent—results that are less impressive than those of the sample as a whole. In 10 cases the comparison was made between each site and a control site with no TDM program, and in 5 cases the comparison was made between each site and conditions found in surrounding subareas.

Of the 22 cases, 16 employer sites reported positive costs, 3 reported negative costs, and 1 reported no costs. Twelve of the 20 sites reported cost savings. The annual net cost per employee for the 20 sites that provided cost or savings data ranged from −$533 to $480, with an average (mean) of −$12.46. This average is the mean of the individual per-employee costs, originally expressed per day, multiplied by 265 workdays (−0.047 × 265). The annual net cost for the sample as a whole (total net cost/total number of employees) is −$63.6 (−$0.24 × 265).

The net cost per one-way trip reduced for the 20 sites that provided cost and savings data range from −$3.32 to $4.99 per trip, with a mean of $0.43. The net cost per trip reduced for the sample as a whole (total cost/total trips reduced) is $0.72. Using cost data only and excluding savings, the direct cost per one-way trip reduced ranges from −$1.95 to $5.62 per trip with a mean of $1.33, whereas the cost per trip reduced for the sample as a whole is $1.22; again, no explanation is given for three employers experiencing negative costs.

It is important to note that the net cost figures reported by Comsis include, in 12 cases, cost savings resulting from the following:

1. Revenues received from the imposition of parking charges or fees, or payments from users of vanpool or other services or programs.
2. Costs avoided in supplying parking to employees, measured in terms of lot and garage space that did not have to be built or maintained, or lease payments for facilities not owned by the employer.
3. Savings resulting from the freeing of land dedicated for parking for other purposes.

The employers highlighted in the Comsis study implemented TDM programs for a variety of reasons. Three employers were under no legal requirement and did so primarily as a way of dealing with the expense or shortage of parking (or both). Six employers are located in the South Coast Air Basin and are therefore subject to Regulation XV, one is located in Ventura County and is subject to Rule 210. The remaining 10 are subject to some form of local ordinance that requires them to limit or reduce parking, implement TDM measures, or both. It must also be remembered that the sample was chosen as a series of case studies rather than as a random sample of employers subject to a specific regulation. Many of the employers were also providing TDM programs to their employee before they were regulated to do so.

In addition to presenting cost-effectiveness data, Comsis also identifies three groups that incur the costs, and benefit from the savings, of implementing or not implementing TDM: society, employers, and individual travelers. The cost to employers was outlined earlier. The cost to society of not implementing TDM can be expressed in terms of the resources needed to increase highway capacity, environmental costs, opportunity costs, wasted time and energy, and reduced productivity. Comsis uses the cost of providing additional highway capacity to illustrate the cost to society of not implementing TDM. Comsis estimates that the cost to supply the highway capacity to serve a single-occupancy vehicle for a 10.5-mi work trip is $6.75, the cost to supply the highway capacity for one transit trip is $4.10 (saving $2.65/trip), a carpool trip is $2.70 (saving $4.05/trip), and a vanpool trip is $0.56 (saving $6.19/trip).

The cost to the individual, for a similar 10.5-mi one-way trip, is estimated by Comsis to be $4.81 for a single-occupancy-vehicle trip, $1.82 for a transit trip (saving $2.99), $1.92 for a carpool trip (saving $2.89), and $0.40 for a vanpool trip (saving $4.41). Comsis summarizes the "compelling economics of TDM" as follows:

Cost or Saving	*Per Trip ($)*
Savings to society	2.65 to 6.19
Cost to employers	−3.32 to 4.99 (average 0.43)
Savings to individuals	2.99 to 4.41

ERNST AND YOUNG

Regulation XV Cost Survey

Ernst and Young was retained by SCAQMD in early 1992 to estimate the annual costs incurred by employers complying with Regulation XV and to estimate the change in employee commute trips associated with those costs. A cost survey was sent to 5,763 regulated work sites and 1,094 surveys were returned—a response rate of 19 percent. Of the 1,094 work sites, 588 had filed their first update (second) trip reduction plan, and 189 had filed their second update (third) plan.

Methodology

Regulated companies were asked to provide cost data for the following cost categories: employee transportation coordinator (ETC) training, plan implementation and maintenance costs (including office space, marketing, facility improvements, incentive costs, and revenues from reduced parking spaces/increased parking charges), and other costs. Unlike Comsis's study, no significant savings data, such as reduced capital expenditure, were included. The self-reported costs were also not audited for accuracy. To measure effect, Ernst and Young used average vehicle ridership (AVR), the ratio of employee commute trips to vehicles arriving at the work site during the survey period. AVR is the primary measure used by SCAQMD to measure the progress of regulated employers.

Several reasons were given as to why the results of the survey may not accurately reflect Regulation XV costs:

1. The survey respondents may have been those at sites experiencing the highest costs and that are therefore most concerned about the regulation.
2. ETCs may have overlooked or overstated some of the costs.
3. Some sites may have offered commute assistance to employees before the regulation and may have included these costs in their estimates.

Although the number of work sites submitting plans declined with each round of updates, Ernst and Young assumed that those respondents that had completed their second update (third) plans were representative of those that had not yet done theirs. These average AVRs were extrapolated to the entire district and, on the basis of experiences of the sample, the number of vehicle trips that will have been eliminated once all the currently regulated employees have progressed to their second update plans was calculated.

Results

Costs

For the 1,094 work sites returning surveys, the total cost of complying with Regulation XV was estimated to be $30,756,402. The cost per regulated employee (i.e., per employee arriving at the work site between 6 and 10 a.m.) for the sample as a whole was estimated to be $105. This was calculated by dividing the total cost by the total number of regulated employees and is not an average of the individual cost per employee figures for the 1,094 sites. The cost distribution of the individual per-employee costs, however, was negatively skewed with 121 work sites spending less than $25/employee, 299 spending between $100 and $200, and 24 spending more than $500.

The annual cost of $105 per employee for the sample as a whole was extrapolated to the total number of "6 to 10" employees in the district, and the total cost of the regulation was estimated to be $162 million/year. This cost estimation, however, assumes that the cost is divided only among those employees who report to work between 6 and 10 a.m. In many cases, however, many employers extend their commute benefits to all employees. The cost per regulated and nonregulated employee for the sample as a whole would be $81/employee. Comsis and CTS used every employee at the work site as the basis for their per-employee costs.

The mean cost per employee is $128 (the sum of the individual per-employee costs divided by 1,094), and the median cost is $88/employee. Thus, depending on the average chosen to extrapolate from, the annual cost of Regulation XV can range from $136 million to $197 million. As noted, Ernst and Young used the per-employee cost for the sample as a whole to arrive at its annual cost of $162 million.

AVR

The average AVR (total number of employees/total number of employee trips) for the 1,094 employers with initial (first) plans filed was found to be 1.20. The average AVR for the 588 employers with update (second) plans filed was found to be 1.24; the average AVR for the 189 employers with second update (third) plans filed was found to be 1.31. To calculate the average AVR for the entire sample at each plan stage, the total number of "6 to 10" employees was divided by the total number of vehicles.

Ernst and Young extrapolated the AVR data from the sample to the entire regulated community and estimated that there will be a decrease of 41,420 vehicles from initial to first update plans (a reduction of 3.2 percent) and an estimated 66,399 reduced from first to second update plans (a reduction of 5.3 percent) by the time all the currently regulated sites have completed their second update plans (a total of 107,819 vehicles or vehicle round trips).

Ernst and Young also estimated that removing the 107,819 round trips in 2 years will cost employers $323 million (2 $162 million). Thus, attributing the entire change in employee travel behavior to Regulation XV, the average annual cost of reducing one vehicle round trip is $3,000 ($323 million/107,819 round trips). Assuming that each employee makes a trip to and from work, the average annual cost per one-way trip reduced would be $1,500. This, however, is the cost of reducing one commute trip every workday for a year. The cost per daily one-way trip would therefore be $5.66 ($1,500/265 workdays). Using a total annual cost extrapolated from the mean or the median cost per employee, however, would result in costs per trip reduced per day of $6.89 and $4.75, respectively. Again, these figures do not take into account any trips outside of the "6 to 10" window that might have been reduced but that were not recorded in AVR surveys.

Analysis of SCAQMD's data base by CTS in March 1993, however, found that for the 1,327 work sites that had submitted second update (third) plans, the average number of regulated employees per site had declined by the first update (second) plan to 94 percent average number in the initial (first) plan; by the second update (third) plan, the number had declined to 92 percent of the regulated employees in the initial (first) plan. These figures indicate that the number of regulated employees has not remained constant, and thus the "per-employee cost" of Regulation XV will vary according to the employee base used.

Follow-Up Study

SCAQMD, concerned with the wide variance in annual per-employee costs (from less than $25 to more than $750), asked Ernst and Young to select 20 of the 1,094 companies (1.8 percent) for further clarification of their survey responses. Ten companies were chosen from the top 50, five from the bottom 50, and five from the middle (those spending about $105/employee. On-site interviews were conducted at 17 companies; 11 were at the high end of the cost range, 3 at the bottom, and 3 in the middle.

Ernst and Young found that 10 of the companies had overstated their costs (*8*). Nine of these fell in the high cost range. Verified cost data were consistent with the data reported in the original cost survey at six sites, and one site had underestimated its costs. For the nine companies that overestimated their costs, the degree of overestimation ranged from 9 to 79 percent. The two most stated reasons for overstatement were that the reported costs related to all employees and not just regulated employees, and that the summary section of the survey (the primary source for raw data) was often completed incorrectly. As noted, at no stage during the original study were the cost data checked or verified for accuracy.

Even though the follow-up study cast serious doubt on the integrity of the original study, no attempt was made by Ernst and Young or SCAQMD to calibrate the original cost data. Legitimately, this would not have been sound because the follow-up sample size was only 1.6 percent of the original sample and because the distribution of the sample bore no relationship to the cost distribution of the original sample. In essence, the results of the original study were negated without revised results being put forward.

COMMUTER TRANSPORTATION SERVICES, INC.

What Price Success? Regulation XV Trip Reduction Plans: Investment Patterns and Cost Effectiveness

In 1991 CTS was the first to analyze SCAQMD's Regulation XV data base in relation to the cost of compliance. The objectives were to attempt to (a) determine the level of investment that an employer would need to make in order to be successful in their effort to increase average vehicle ridership and (b) identify the TDM strategies that appeared to produce the greatest return on investment.

Methodology

The 769 employers that had submitted initial (first) and first (second) update trip reduction plans to SCAQMD as of April 1991 were ranked in order of success. Success was measured in terms of increase in AVR. The 65 top-ranking CTS clients were identified and surveyed by CTS to determine plan implementation costs. Completed cost surveys were returned by 37 companies (57 percent), and follow-up telephone calls were made to confirm the data. Data were collected for the following cost categories: ETC salary, guaranteed ride home, marketing, facility improvements, parking management, company vanpool, indirect incentives (prizes, benefits, and services), and direct incentives (subsidies). Like Ernst and Young, CTS did not include savings from reduced capital costs, such as savings from not having to build additional parking spaces.

Each of the 37 employers in the study was very successful in increasing AVR from its initial to first update plan. The purpose of the study was to determine how much it costs to be "successful" and not how much it costs the average employer, regardless of success, to operate a TDM program. The AVR calculation includes "nonresponses," which are automatically treated as single-occupancy vehicles, and compressed workweek and telecommuting responses, which are treated as no vehicles. This means that a difference in the nonresponse rate from one plan to the other can positively or adversely affect AVR without there actually being any change in driving behavior. Alternative schedule responses also raise AVR without, in these 37 cases at least, there being any cost associated with them.

Thus, to analyze cost in relation to AVR change, a modified AVR (MAVR) was calculated that excluded nonresponses and alternative schedule responses. The MAVR also corrected for inconsistencies in the reporting of car and vanpool size by assuming that all carpools carried 2.5 persons and all vanpools 10.5 persons.

Results

The most successful employer succeeded in raising its MAVR by 56 percent; the least successful experienced a reduction in MAVR of 2 percent (the increase in AVR was primarily accounted for by alternative schedules). The average annual investment per transportation program, as reported by the 37 employers, was $29,000, with a range from $1,500 to $133,400. Investment per employee for each of the 37 employers was also calculated, using the average number of workers at the site during the period and not only the number of regulated employees as per updated plan. The per-employee cost was found to range from $6 to $450. The average (mean) of the 37 cost-per-employee figures was found to be $70 (the sum of the individual per employee costs at Sites 1 through 37 divided by 37). The cost per employee for the entire sample, calculated by dividing the total cost by the total number of employees, was $57, whereas the median per employee cost was $32. Unlike Ernst and Young's study, however, the choice of an "average" was not so critical for CTS since no attempt was made to extrapolate the results.

Analysis of MAVR relative to investment found there to be no relationship between the variables. In other words, big spenders did not necessarily achieve large increases in AVR, and low spenders were not necessarily low achievers. This finding may disappoint those who are looking for a formula for success or for an answer to the question of how much they need to spend, but it is good news for those willing and able to experiment and find out what works best and costs the least for them. Analysis of investment in any one incentive and change in MAVR also did not reveal any relationships. This finding is consistent with Comsis's work for SCAQMD that, with analysis of 5,000 employers in the SCAQMD data base, could not isolate the factors that explain change in commute behavior or assess the impact of any one incentive (*9*).

CTS's original study did not provide a cost per trip reduced; however, reanalysis of CTS's data found the average cost per one-way trip reduced for the 37 employers was $397 for the sample as a whole with a range from $33 to $4,785. The mean cost per trip reduced, however, was $431. As noted, however, unlike Comsis's costs and like Ernst and Young's, these figures do not include cost savings that may result from reduced capital expenditure.

PROBLEMS INHERENT IN CONDUCTING COST-EFFECTIVENESS STUDIES

As one would expect, the primary difficulties in conducting cost-effectiveness studies are, first, isolating cost and effect and, second, determining causal relationships between the two. The studies have illustrated that there are a number of ways to collect and treat cost data and a number of ways to measure effect. The following section seeks to outline some of the inherent difficulties involved in collecting and analyzing cost and effect data and in determining cost-effectiveness.

Determining Cost

The primary difficulties in determining the cost of individual employer-based vehicle trip reduction programs and strategies are as follows:

- Often little or no cost data are available.
- It is often difficult to determine when, and over how long a period, an expense was incurred and, in the case of capital expenditures, to determine the rate of depreciation.
- The costs and savings categories vary from employer to employer and study to study.
- Some costs, such as administrative costs and staff time, are difficult to determine.
- Many costs are buried in corporate overhead and are difficult to quantify.
- The cost of any one incentive is difficult to determine because the cost of marketing and administration is difficult to apportion.
- Some expenditures may not be entirely TDM-related.
- The same strategies can be offered at different costs by different employers.
- The marginal cost of reducing one additional employee trip can be greater than the reward that the employee actually receives.

Determining the aggregate cost of employer-based trip reduction programs, or determining the cost of a particular regulation, is also problematic for the following reasons:

- When a sample is used to extrapolate costs, the sample may not represent the whole.
- The estimated cost of a strategy varies according to the "average" used. For example, the average cost for the sample as a whole can be different from the mean of the costs of the individual programs, which in turn can be different from the median or mode.

Determining Effect

The primary problems inherent in determining the effect of employer-based TDM programs or strategies are as follows:

- There are a number of ways to measure effect (e.g., number of trips reduced, vehicle miles reduced, pounds of pollutants reduced), and each one requires different data.
- To measure the effect of a particular program or strategy, a base level must be determined. This requires that comparable, accurate pre-data or a suitable control be available.
- The effects of individual strategies are difficult to isolate from overall effect.
- An effect may be measured but it is often difficult to determine what caused it; for example, many factors, in addition to the program itself, can influence employee travel behavior.
- Some incentives, such as a guaranteed-ride-home program, may be necessary to encourage employees to take advantage of other incentives, but they may not directly cause behavior change.

Determining Cost-Effectiveness

The primary measures used to assess the cost-effectiveness of employer-based trip reduction programs are cost per employee and cost per trip reduced, and, as noted, there are a number of problems inherent in determining cost, number of trips reduced, and number of employees to use as basis for per-employee costs.

Cost-effectiveness can also be measured in several ways—for example, cost per pound of pollutants reduced or cost per vehicle mile reduced. To make these assessments, however, data such as trip length, number of cold starts, and make, model, and year of car must be known for each employee. The cost-effectiveness of Regulation XV, since its primary purpose is to improve air quality, should probably be measured in terms of pounds of pollutants reduced but, as yet, the necessary data do not exist.

Cost-effectiveness is also a relative term in the sense that a particular strategy is only more or less cost-effective when compared with another. Unfortunately, however, even if it is determined that a particular strategy is less cost-effective than another, it does not necessarily follow that the less cost-effective measure should be abandoned because it may target areas, individuals, or organizations that are not covered by the other measure; a variety of measures are often needed to address the same issue. The most cost-effective strategy may also not be the most politically acceptable.

Cost-effectiveness figures also assume that the expenditure is responsible for the effect. In reality, one cannot necessarily assume that money alone is responsible for a particular result. Lopez-Aqueres identifies "program resources" as only one variable in a myriad of dependent and independent variables that can affect the outcome of a trip reduction program (*10*). Other variables include

- Public policy factors: federal and state income tax codes, labor legislation, public transportation system, land-use regulations, federal and state gasoline taxes, and education;
- Employer factors: management commitment, program incentives/disincentives, labor-management agreements, work site location, and employer size;
- Employee characteristics: personal values, occupation, commute distance, and household characteristics; and

• Travel mode characteristics: travel cost, travel time, convenience, comfort, privacy, and safety.

Thus, it appears that further analysis of TDM cost-effectiveness should consider these factors. The determination of the relative weight of each variable, however, requires that the relative importance of each variable be known—which, as yet, is not.

Finally, even if these difficulties could be overcome and satisfactory cost-effectiveness figures arrived at, there would remain one problem: cost-effectiveness figures can always be "massaged" to prove almost any point. Including or excluding social costs, for example, is a classic strategy for dramatically increasing or decreasing the cost-effectiveness of a particular strategy.

Despite inherent problems, the need to evaluate the cost-effectiveness of employer-based trip reduction programs remains, and efforts to do so continue. Thus, while this paper highlights difficulties in conducting such studies, it is not meant to discourage future work; instead, its purpose is to encourage future research by providing an overview of the work conducted so far and highlighting the critical issues and problems to be addressed in future research.

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Commuting Stress, Ridesharing, and Gender: Analyses from 1993 State of the Commute Study in Southern California

RAYMOND W. NOVACO AND CHERYL COLLIER

A stressful nature of exposure to traffic congestion in automobile commuting has been demonstrated in previous quasiexperimental research that has been measurement-intensive but conducted with relatively small samples. Commuting stress in automobile travel is examined with a large representative sample (N = 2,591) in Southern California through a telephone survey. Commuting stress was found to be significantly associated with distance and duration of the commute, controlling for age and income. As predicted, the stressful effects of long-distance commutes (greater than 20 mi) were further moderated by gender, as women in such commutes perceive much greater commuting stress spillover to work and home. Some hypothesized stress-mitigating effects of ridesharing were found, as full-time ridesharers were significantly less bothered by traffic congestion and more satisfied with their commutes than solo drivers. In analyses of prospective adoption by solo drivers of alternative commuting modes, it was found that the perception of one's commute as having a negative impact on family life had a very significant effect on the inclination to try carpooling and rail, beyond the effect associated with distance itself. Commuting stress is discussed as an external cost of traffic congestion that is internalized by the solo driver. Marketing strategies for alternative modes of commuting might increase their effectiveness by highlighting stress consequences, especially negative impacts on family life.

Among the external costs believed to be associated with traffic congestion are the effects of stress on humans. Remaining attached to the mode of private automobile travel and constrained by the availability of affordable housing, workers endure congested commutes and absorb the stressful consequences. Indeed, the stressful effects of chronic exposure to traffic congestion and other demands of long-distance driving in commuting between home and work have been demonstrated in a series of studies (*1–3*). In these studies, traffic congestion has been understood to be stressful by virtue of its impedance properties. That is, it operates as a behavioral constraint on movement and goal attainment, thus constituting an aversive, frustrating condition. As such, it elevates physiological arousal, elicits negative emotional states, and impairs cognitive performance. This research has found that high-impedance commuting, indexed by objective and subjective dimensions, has harmful effects on blood pressure, mood, frustration tolerance, illness occasions, work absences, job stability, and overall life satisfaction.

The methodology used in this research program on commuting stress has been a measurement-intensive, quasiexperimental field site testing procedure that incorporated many control variables as covariates in the analyses. However, this methodological rigor has come at the expense of assurances about the ability to generalize, because of the relatively small sample sizes (each of these previous projects has involved approximately 100 participants) and the location (all studies were conducted with companies in one city).

The present study, therefore, examined commuting stress associated with automobile travel in a much larger geographic area with a large representative sample of commuters. For this purpose, several items pertaining to commuting stress were added to the Southern California 1993 State of the Commute survey. Collier and Christiansen have reported on the results of this survey in previous years (*4,5*). The newly added items sought to index commuting stress in terms of the aversiveness of the commute and the negative impact of traffic exposure on work and home life.

Ridesharing has been promoted as an alternative commuting mode to reduce traffic, air pollution, and stress. The present study also examined the merit of ridesharing in comparison with solo driving regarding the stress effects of long-distance commuting. National trends in commuting patterns have indicated that increases in the work force, the availability of automobiles, and the shift of jobs to suburban locations have significantly increased commuting by private automobile (*6*). From 1960 to 1980, travel to work by private automobile increased from 70 to 85 percent nationally, whereas the use of public transit declined from 12.6 to 6.2 percent (*6*). Although increased congestion and air quality management regulations have prompted ridesharing programs, Teal has shown with national data that the large majority of drive-alone commuters lack any transportation or economic motivation to carpool (*7*).

In California, road use charges are virtually nonexistent, gasoline remains inexpensive, and nearly everyone who needs a car has one. The impact of the latter is illustrated by the fact that from 1980 to 1989, many California counties have had a greater proportionate increase in registered automobiles than in population. For example, the population of San Francisco County increased by 50,400 (7.4 percent) during those years, yet the number of registered automobiles increased by 49,835 (18.8 percent). The corresponding figures for Santa Clara County were 154,200 (12 percent) people and 183,643 (25.4 percent) automobiles; for Los Angeles County 1,205,900 (16.2 percent) people and 870,191 (23.6 percent) automobiles; and for Orange County 357,900 (18.6 percent) people and 330,621 (30.8 percent) automobiles.

As far as reducing the demand for road space, transportation alternatives to solo driving in Southern California have made only small gains. Analyses of the first-year results of the trip reduction mandated by Regulation XV (*8,9*) found that average vehicle ridership (AVR) increased from 1.213 to 1.246 (although there was considerable variation across sites) and that "(t)he number of work sites meeting the target AVR actually decreased during the

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first year of the program." Increased carpooling accounted for virtually all of the increase in AVR. The Giuliano et al. data from employment sites found the solo driving mode to be at 71 percent during mid-1991, but the Collier and Christiansen State of the Commute survey (*5*) found the drive-alone rate to be 77 percent at regulated sites across Southern California counties, continuing the national trend of solo-driving commuting noted by Pisarski (*6*) and Liss (*8*). To the extent that ridesharing mitigates commuting stress, marketing strategies might then be devised that highlight this benefit and be targeted toward the population sectors that are most at risk or that are otherwise sensitized to stress themes.

Regarding the question of at-risk or sensitized population sectors, the previous research on commuting stress has examined the hypothesized moderating role of gender, whereby commuting stress impacts in the residential domain were expected to be greater for females commuting on routes of high-physical-impedance. Reasoning from a convergence of findings in the three areas of travel behavior, workers' stress physiology, and work effects on family life, Novaco et al. (*3*) expected that female high-impedance commuters [>20 mi (32.2 km); >50 min on p.m. commute] would be highest on residential domain stress measures. This hypothesis was strongly confirmed across multiple measures and analyses, which rigorously controlled for potentially confounding factors as covariates.

The significant effects for high-impedance females, relative to their male counterparts, were obtained for measures of dysphoria, general spirits, satisfaction with location, desire to move, and ratings of the home physical environment; although not statistically significant, the results were in the expected direction for negative mood at home, satisfaction with dwelling, and satisfaction with neighborhood. Indeed, women in the high-physical-impedance commutes appraised their commutes more negatively than did men in the same condition, despite these women having higher family incomes and not differing in education, marital status, or home ownership; nor did they differ in the objective characteristics of their commutes. However, these high-physical-impedance females reported considerably more constraint than did men, particularly for the a.m. commute; they reported being delayed more often by traffic jams, being less able to avoid traffic, and being less satisfied with their commutes. They did not, however, have more complex travel segments than did the high-impedance men in that study, hence Novaco et al. (*3*) speculated that differential role strain (work and household responsibilities) might be an explanatory factor.

Whereas the effort to explain previously obtained gender effects is an important research agenda, it is also imperative that the question of gender differences in commuting stress be examined with a much larger representative sample. Hence, this issue is pursued in the present study with the 1993 State of the Commute Survey. Gender effects were examined in various statistical designs with commuting mode (solo driving, part-time ridesharing, and full-time ridesharing) and distance (as a continuous measure and as categorically partitioned).

METHOD

Survey Design and Procedure

The State of the Commute is an annual study conducted by Commuter Transportation Services, Inc. (CTS). The 1993 State of the Commute study is based on a telephone survey of 2,591 commuters within Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties. Respondents surveyed included only commuters who work full-time and excluded those for whom the home is a primary work site. The survey provides updated information on commuters' travel behavior and attitudes about traffic congestion, alternative travel modes, employer transportation programs, and high-occupancy vehicle lanes.

CTS contracted Interviewing Services of America, Inc. (ISA) to draw a sample based on random-digit dialing using their copy of Genesys's sampling program. This method, rather than directories, is used because of the high proportion of unlisted telephone numbers in the Los Angeles area. Random-digit dialing avoids the bias introduced by using only listed telephone numbers. An extensive cleaning and validation process was undertaken to ensure that all phone numbers in Genesys's data base were assigned to the correct area code and to increase the probability of reaching a working residential number.

ISA was also contracted to perform data collection. The survey questionnaire was pretested by interviewers from ISA. Since the majority of the survey questions were consistent with previous surveys, only minor formatting changes were made.

From October 9 to December 7, 1992, ISA's interviewers, using a computer-assisted telephone interviewing (CATI) system, contacted respondents in the five-county area. The use of a CATI system ensures strict adherence to skip patterns, eliminates key entry errors, and allows for extensive quality control. No interviews were conducted between November 19 and November 30 due to the unpredictable travel patterns near the Thanksgiving holiday. A minimum of three call-back attempts were made. English and Spanish versions of the questionnaire were available to meet the language requirements of respondents. Five hundred and twenty-five interviews were completed in each county in order to make county comparisons possible. A 4.5 percent sampling error is normally associated with sample sizes of 500. Regionally, 2,591 interviews was used in the analysis. A 2 percent sampling error is normally associated with sample sizes of 2,500.

Each interview began with the screener question, "How many persons 18 years or older in your household work full-time outside the home?" Actual selection of eligible respondents was based on the person who had the most recent birthday. This process was used in order to avoid the possible bias of surveying a disproportionate number of women and children, since they are most likely to answer the telephone. Once interviewing had been completed, responses were weighted by the number of eligible respondents within each household. This ensures that small households are not overrepresented in sample statistics. Furthermore, for the analysis at the regional level, data were additionally weighted by the working population in each county based on 1990 U.S. Census figures.

Commuting Stress Measures

Four survey items constituted the commuting stress indexes. "Commuting satisfaction," rated on a nine-point scale, has been a item in previous State of the Commute surveys (*4,5*), and a similar item has been a component of the subjective impedance indexes in the Novaco et al. studies (*2,3*). Thus, it is here incorporated as a stress index. Three other items, rated on five-point scales, were newly composed for the 1993 State of the Commute study: "How often do you feel bothered by traffic congestion in commuting to or from work?"; "After your commute to work, how often do you feel a need to wind down and relax before starting work?"; and "Some people say that dealing with traffic on their commute home from work has a negative effect on their home life. To what extent is this true for you?" The first of these new items is intended to assess the aversiveness of the commute. Aversiveness of travel has been a principal components factor in the subjective impedance measures of Novaco et al. (*2,3*). The other two items aim to assess work and home domain impacts that are part of the commuting stress construct. Although it is less than optimal to operationalize the construct with these four simple items, the pragmatics of survey research demand simplicity.

Hypotheses and Analytical Procedures

1. Commuting stress indexes were expected to be correlated significantly with distance and duration of the commute, controlling for age and income. This was examined by simple correlation and in multiple regressions with the control variables.

2. Consistent with the concept of impedance, commute duration was expected to be a stronger predictor of stress than would be commute distance. Commute time to work was expected to be the strongest predictor of the work arrival stress measure ("need to wind down"), whereas commute time home was expected to be the strongest predictor of the home stress measure ("negative impact on family life").

3. Following the rationale and results of the Novaco et al. (*3*) study, females commuting a long distance (20+ mi; 32.2 km) were predicted to have higher commuting stress than men—that is, females would be less satisfied with their commute, be more bothered by traffic congestion, report a greater need to wind down on arrival at work, and perceive a greater negative impact on their family life. This prediction was tested in a 2 × 2 (distance × gender) analysis of variance (ANOVA). In addition to the interest in replication of the previous research, distance rather than duration is used as the commuting condition factor because it is a more stable attribute of the commute. Drivers may indeed vary their routes, but commute distance fluctuates less than does duration, which is affected not only by road conditions but also by ridesharing.

4. Ridesharing is expected to buffer the stress effects of commuting, especially in the case of long-distance commutes (20+ mi), comparing full-time ridesharing to solo driving. No predictions were made for part-time ridesharers. This was examined in a 3 × 2 ANOVA design (commute mode × distance) and post-hoc comparisons (Scheffe tests) of the solo driver and full-time ridesharer means for the stress indexes.

RESULTS

The average commute distance for the sample is 23.8 km (14.8 mi), and the average commute durations were 28.7 min to work and 32.3 min to home. Because various grouping conditions were defined by mile criteria, they are designated in the text below in mile units. Consistent with Hypothesis 1, the commuting stress indexes are significantly related to the distance and duration attributes of the commute, which are much more strongly associated with the stress measures than are age and income. These correlations are given in Table 1 for the full sample. Table 2 partitions the sample according to automobile commute mode (solo driving, part-time ridesharing, and full-time ridesharing) giving the correlations of the stress measures with miles and minutes to work.

TABLE 1 Correlations of Objective Travel and Demographic Indexes with Commuting Stress Measures (1993 State of the Commute Survey; N = 2,591)

	Satisfaction With Commute			How Often Bothered By Traffic Congestion			Need To Wind Down After Commute To Work			Dealing With Traffic Has Negative Impact On Family Life		
	Males	Females	Total	Males	Females	Total	Males	Females	Total	Males	Females	Total
Miles to Work	-.25**	-.32**	-.29**	.25**	.34**	.29**	.13**	.26**	.18**	.19**	.25**	.21**
Minutes to Work	-.33**	-.36**	-.35**	.34**	.41**	.38**	.20**	.33**	.26**	.20**	.30**	.24**
Minutes to Home	-.35**	-.35**	-.35**	.32**	.43**	.37**	.18**	.29**	.23**	.20**	.32**	.25**
Age	.08*	.07	.07**	-.04	-.10*	-.07*	-.07	-.16**	-.11**	-.05	-.14**	-.10**
Income Level	-.08*	-.02	-.06*	.14**	.07	.11**	-.07	-.12**	-.09**	.03	.01	.02

* p < .01 ** p < .001

TABLE 2 Correlations of Objective Travel Indexes with Commuting Stress Measures for Solo Drivers, Part-Time Ridesharers, and Full-Time Ridesharers (1993 State of the Commute Survey; N = 2,591)

	Satisfaction With Commute			How Often Bothered By Traffic Congestion			Need To Wind Down After Commute To Work			Dealing With Traffic Has Negative Impact On Family Life		
Mode Groups	Males	Females	Total	Males	Females	Total	Males	Females	Total	Males	Females	Total
Solo Drivers (n=1914)												
Miles to Work	-.34**	-.33**	-.34**	.28**	.34**	.31**	.16**	.28**	.20**	.19**	.28**	.21**
Minutes to Work	-.40**	-.37**	-.39**	.34**	.45**	.39**	.20**	.38**	.28**	.23**	.34**	.28**
Part-time Ridesharers (n=141)												
Miles to Work	-.16	-.44**	-.29*	.24	.18	.21	.33	.24	.28*	.51**	.07	.24*
Minutes to Work	-.27	-.56**	-.42**	.43**	.04	.21	.33*	.08	.21	.43**	.03	.15
Full-time Ridesharers (n=536)												
Miles to Work	.09	-.27**	-.08	.06	.42**	.23**	.02	.20*	.10	.10	.27**	.18**
Minutes to Work	-.14	-.29**	-.22**	.36**	.43**	.40**	.23*	.22*	.23**	.04	.27**	.16*

* $p < .01$ ** $p < .001$

It can be seen that for solo drivers the magnitude of each correlation is stronger than the corresponding coefficient in the full sample, except one for which it is the same. Except for the part-time ridesharers, the magnitude of the correlations is generally stronger for females than for males. There is some indication in the set of coefficients in Table 2 that full-time ridesharing attenuates the correlation between commute attributes and the stress measures, but this is more properly assessed in the ANOVA tests of group means reported later.

The differential effects stipulated in Hypotheses 1 and 2 were tested by multiple regressions performed with age and income as control variables entered on the first step, and then the distance and duration measures entered as predictors in separate equations. For "commute satisfaction," time to work accounts for 12.2 percent of the variances (R^2 change = .122, T = 16.3, df = 3,2157, $p < .0001$) that are associated with the covariates of age and income, which together account for 1 percent. The R^2 change effects for time home and for distance are .108 and .075, respectively, which both are also highly significant ($p < .0001$). The effects follow a similar pattern for the other stress variables regressed with the covariates of age and income: "bothered by traffic" is most strongly related to time to work (R^2 change = .134, T = 18.5, df = 3,2193, $p < .0001$); "need to wind down on work arrival" is most strongly related to time to work (R^2 change = .063, T = 12.2, df = 3,2181, $p < .0001$); and "negative impact on family life" is most strongly related to time home (R^2 change = .057, T = 11.5, df = 3,2176, $p < .0001$). These findings are supportive of the authors' predictions of differential effects.

Analyses of the effect of distance (low versus high) were examined in a 2 × 2 ANOVA design with gender. The means, standard deviations, and ANOVA results are presented in Table 3. The distance effect is very highly significant for all of the stress indexes. Significant gender differences were found only for commuting satisfaction; women are more satisfied than men. The interaction of distance with gender was highly significant for the need to wind down on arrival at work and for perceived negative impact on family life. The interaction is more exactly an additive effect, showing the moderating influence of gender on the effect produced by distance. Women in the long-distance commutes perceive much greater commuting stress spillover to work and home.

The hypothesized mitigating influence of ridesharing on the stress-inducing effects of distance are presented in Table 4. There is a significant commuting mode main effect on the "satisfaction," "bothered," and "need to wind down" indexes, as indicated by the ANOVA tests given in the table. (At this time the authors are not presenting the results of a three-way analysis that included gender because of the complexity of the interactions.) Regarding the two-way analysis (distance × mode), because the differences between means on the stress variables are partly due to the part-time ridesharers, post-hoc Scheffe tests were performed to compare the solo drivers with the full-time ridesharers, so as to examine Hypothesis 4. Summing across distance conditions, the full-time ridesharers, compared with the solo drivers, are significantly higher in commuting satisfaction and less bothered by traffic congestion ($p < .05$ for both Scheffe tests). Thus, Hypothesis 4 was only partly confirmed.

TABLE 3 Commuting Indexes as a Function of Distance and Gender

Commuting Stress Indices	Distance (<20) Males n=943	Distance (<20) Females n=1004	Distance (>20) Males n=326	Distance (>20) Females n=189	Analyses of Variance $F_{(D)}$	$F_{(G)}$	$F_{(DxG)}$
Satisfaction with commute	6.5 (1.9)	6.8 (1.8)	5.5 (2.1)	5.6 (2.1)	124.4	6.4	NS
Bothered by Traffic Congestion	2.8 (1.3)	2.7 (1.2)	3.5 (1.4)	3.6 (1.3)	130.4	NS	NS
Need to Wind Down on Arrival at Work	2.0 (1.3)	1.9 (1.2)	2.3 (1.4)	2.7 (1.5)	62.0	NS	17.2
Negative Effect on Family Life	1.6 (1.0)	1.6 (1.0)	2.0 (1.1)	2.3 (1.3)	78.2	NS	11.4

Note: The "satisfaction with commute" measure is a nine-point scale; all other indices are on five-point scales. Standard deviations are given in parentheses below the means. All F ratios given in right-side section for distance (D) and the interaction (DxG) are significant beyond $p < .001$. The one gender (G) effect is significant at $p < .02$.

TABLE 4 Means of Commuting Stress Indexes as a Function of Mode and Distance

Commuting Mode	Satisfaction with Commute	How Often Bothered by Traffic Congestion	Need to Wind Down After Commute to Work	Dealing with Traffic Has Negative Impact on Family Life
Solo Drivers				
Distance ≤20 (N=1447)	6.7	2.8	1.9	1.7
Distance >20 (N=407)	5.4	3.6	2.4	2.1
Part-time Ridesharers				
Distance ≤20 (N=127)	6.4	2.8	2.2	1.6
Distance >20 (N=12)	5.5	3.5	3.2	2.5
Full-time Ridesharers				
Distance ≤20 (N=373)	6.7	2.6	2.0	1.5
Distance >20 (N=100)	6.1	3.4	2.4	2.1

Note: There is a highly significant ANOVA main effect for distance on all four stress indices (F = 64.6 to 136.2, $p < .0001$); there is a commuting mode main effect for "satisfaction" ($F = 3.4$, $p < .04$), "bothered" ($F = 4.5$, $p < .02$), and for "wind down" ($F = 3.7$, $p < .03$). The interaction is significant for "satisfaction" ($F = 4.0$, $p < .02$). There are also a number of interactions with gender, which are not tabled here due to complexity of presentation.

DETERMINANTS OF PROSPECTIVE RIDESHARING

The authors further examined the effects of distance, gender, and stress on solo drivers' endorsement of alternative commute modes. Table 5 presents the percentage of respondents, grouped according to distance ranges (1–6 mi, 7–14 mi, 15–29 mi, and 30 + mi) and gender, who stated that they would definitely try the various alternative commuting modes (carpool, vanpool, bus, train). These distance ranges were selected to optimize the distribution of respondents. The survey question, asked for each mode, was "Would you consider commuting by ____for 1 or 2 days a week to see if you like it?" The response options were "definitely try," "might try," and "not try." (If commute distance was less than 21 mi, the vanpool question was not asked.) As the chi-square tests given in Table 5 indicate, there are significant effects for distance and gender for carpooling and for rail. The disposition to try carpooling and rail modes increases significantly with a commute of 15 mi (24.15 km) or more, especially for women in the very long distance range. In contrast, men in commutes of 30 mi or more have a decreased inclination to try the alternative modes than those in commutes from 15 to 29 mi.

Finding this significant effect for distance on the disposition to try alternative commute modes, the authors then examined whether the experience of stress would add to this inclination. Given the findings of previous research on home environment consequences of commuting stress (*3*), the "negative impact on family life" index was of particular interest. Selecting for long-distance solo drivers having commutes greater than 15 mi (for comparison with the data in Table 5 and to get a sufficient *N* for the analysis), this subset of respondents was then partitioned into those reporting "low negative impact" (a recoding of "not at all," "a little," and "somewhat" responses) versus those reporting "high negative impact" (a recoding of "fairly much" and "very much" responses). These low-high groupings were then crosstabulated with the disposition to try commuting alternatives, performed separately for each commute mode, for each gender, and across genders. In Table 6 are the percentages of respondents in each column category who endorsed the "definitely try" response, separately tabulated for each commute mode alternative. The effect of the stress variable is significant for both males and females in the case of carpooling and for rail. The chi-square tests are given in the table. The effect of family life impact is especially strong for females with regard to carpooling. Nearly 48 percent of the women solo drivers in long-distance commutes who perceive that exposure to traffic congestion has a negative impact on their family life indicate that they would definitely try carpooling. This is a considerably greater percentage than that found for the long-distance condition itself.

DISCUSSION OF RESULTS

The authors have found that commuting stress is significantly associated with the distance and duration of commuting, controlling for age and income. This study then replicates with a large representative sample of Southern California commuters some of the main research findings of previous research on this topic conducted with small samples in one city. The finding that commute duration was more strongly related to the stress measures is consistent with the concept of impedance, as developed in the previous work done by Novaco and his colleagues. In other analyses with this data set, the authors are examining degree of impedance in terms of variation in commute duration at fixed distance points (shorter versus longer time to travel the same distance), and preliminary findings are strongly supportive of the stress propositions. This will be addressed in a subsequent paper.

TABLE 5 "Definitely Try" Responses for Alternative Commuting Modes as a Function of Commute Distance and Gender

	Distance Categories											
	1-6 Miles (N=606)			7-14 Miles (N=512)			15-29 Miles (N=420)			30+ Miles (N=287)		
	Males	Females	Total	Males	Females	Total	Males	Females	Total	Males	Females	Total
Definitely Try:												
Carpool	15.7%	15.9%	15.8%	10.8%	14.6%	12.7%	27.7%	19.5%	24.2%	19.6%	33.2%	24.4%
Vanpool	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	26.5%	18.3%	23.9%	13.2%	30.0%	19.0%
Bus	9.7%	6.3%	7.7%	10.9%	4.3%	7.6%	9.7%	10.5%	10.0%	8.3%	7.8%	8.1%
Train/Rail	9.5%	10.7%	10.2%	13.9%	20.9%	17.4%	27.3%	22.3%	25.2%	14.8%	31.8%	20.7%

Note: The distance categories were partitioned to optimize the distribution of respondents. The tabled percentages are the proportion of respondents in that distance range who state that they would "definitely try" the given commuting alternative (other response options were "definitely not" and "maybe try"). Crosstabulation analyses of the distance effect for the total sample were significant for carpooling, X^2 (df = 6) = 48.6, $p < .0001$, and for train/rail, X^2 (df = 6) = 55.4, $p < .0001$. It is also significant for each gender for these same two commute alternatives ($p < .0001$).

TABLE 6 "Definitely Try" Responses for Alternative Commuting Modes as a Function of Perceived Impact on Family Life and of Gender Among Long-Distance Commuters

	Low Negative Impact on Family Life			High Negative Impact on Family Life			Chi Square Analyses (df=2)		
	Males n=386	Females n=238	Total n=623	Males n=40	Females n=44	Total n=83	X^2_M	X^2_F	X^2_T
Carpooling	23.4%	20.2%	22.1%	33.5%	47.9%	41.2%	8.8	16.8	15.5
Vanpooling	16.9%	24.1%	19.1%	23.8%	39.5%	32.3%	*ns*	*ns*	*ns*
Bus	9.6%	8.6%	9.2%	3.3%	15.8%	9.5%	*ns*	*ns*	*ns*
Train/Rail	20.2%	25.2%	22.1%	39.9%	29.3%	34.1%	8.3	7.3	7.2

Note: This "long distance" subsample was selected for distance = 15 miles or more, in order to have a sufficient number of respondents for testing the family life variable and for comparison with the effects of distance by itself, given in Table 4. The "high negative impact" category here is composed of respondents reporting "fairly much" or "very much" (ratings 4 and 5 on a five-point scale) for the family life stress variable. The "low negative impact" group are those respondents reporting "not at all," "a little," and "somewhat." The tabled percentages are the proportions of respondents in each of these groupings who state that they would "definitely try" the respective commuting alternatives. The chi-square tests are given on the right.

The moderating effect of gender still remains to be understood, because the authors did have some mixed results regarding their gender hypothesis and because understanding the explanatory factors requires further analysis of the data set. Contrary to the authors' predictions, women overall were more satisfied with their commutes than were men, although this effect for commute satisfaction is primarily in the shorter-distance condition. In contrast, a number of the analyses found stronger stress effects for women than for men. In the long-distance commutes, women report a greater need to wind down upon arrival at work and perceive greater negative impacts on family life. The factors that might explain these effects remain to be examined. Travel elements of the commute itself, differential sensitivity to commute aversiveness, and role strain are among the areas for examination. It is known that women's commute trips tend to be more complex than those of men, and variables associated with child care and other household responsibilities need disentangling.

Some evidence was found that supported full-time ridesharing as a buffer of commuting stress, but such results occurred only for two of the four stress indexes. The failure to find greater support for a ridesharing effect may in part be a function of the few stress measures used, which was determined by feasibility. It can also be expected that people select into their commute modes and psychologically adapt to them. Curiously, there were some indications that part-time ridesharers may be acutely sensitive to commuting stress and may be unsatisfied with their ability to mitigate it. The characteristics of this group need to be examined more fully, particularly as demographic and household variables may be entangled with part-time ridesharing. The significant effects for higher commuting satisfaction and being less bothered by traffic congestion found for full-time ridesharers are encouraging for ridesharing program efforts.

The effect of the sensitivity to family life stress in boosting the inclination to try alternatives to solo driving among those commuters who travel relatively long distances to work suggests that marketing strategies for ridesharing and for train commuting highlight these potential stress consequences. Concern with the quality of family life is a salient theme in contemporary American society, and it would seem to be efficacious for transportation management practitioners to call attention to the psychological stress costs to the family associated with time-intensive, long-distance solo driving, especially for female commuters.

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Jitney Enforcement Strategies in New York City

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The findings with regard to jitney enforcement efforts in New York City and their applicability to Dade County, Florida, are documented. The issues are remarkably similar in both places, although the origins and evolution of jitney service are different. Information is drawn from several printed documents prepared by the New York City Transit Authority (NYCTA) and its parent organization, the Metropolitan Transportation Authority (MTA) and from the interviews conducted in New York. The interviewees included representatives from NYCTA and MTA, the Amalgamated Transit Union in the borough of Queens, the offices of the mayor and of a congressional representative, transit and city police, a major legal van operator in Queens, and a consultant who has worked extensively in support of the jitneys. It is concluded that enforcement can work effectively if combined with service improvements or fare reductions. Integration of the jitneys into the public transportation network is a desirable long-term goal, although the means of integrating the jitneys are not yet clear. A successful resolution of the jitney issue will involve cooperation with the transit unions. Even if integration is achieved, there will still be a need for enforcement efforts.

The Center for Urban Transportation Research (CUTR) has undertaken a study for metropolitan Dade County, Florida, to examine jitney enforcement strategies in other major cities in the United States in which legal and illegal jitneys are in service. Jitneys are defined as passenger vans that seat 20 persons or fewer and operate by picking up and discharging passengers along major streets for an established fee. There is a lengthy history in Dade County of authorized jitney service in particular neighborhoods and travel corridors. Over the past several years, Metro-Dade Transit Agency (MDTA, the public transportation operator in Dade County) has suffered declining ridership on bus routes on which competing illegal jitney service has arisen and made major inroads.

In the wake of Hurricane Andrew, metropolitan Dade County received a federal grant to provide local transportation for residents in the hard-hit southern portion of the county. MDTA made arrangements to hire all qualified jitney operators to serve specific areas of southern Dade County under MDTA supervision. Along with improving transportation in the hurricane-ravaged areas, this action resulted in noticeable improvements in ridership on MDTA routes on which jitneys had previously operated. At the end of the federal grant in August 1993, MDTA was to devise a policy for dealing with the formerly illegal jitneys.

Specific issues considered in this study are how jitney service has developed in other cities, what (if any) enforcement actions have been tried in these cities, the success of these enforcement efforts, and the overall strategy (in place or under consideration) to deal with the jitneys. The results provide a different perspective for viewing Dade County's jitney service and various enforcement actions that have been taken.

Several transit agencies around the country were contacted to determine which cities to include in this study. Transit and planning personnel in Chicago, Los Angeles, Atlanta, and Houston indicated that jitneys were not operating in any extensive or organized fashion in their cities. New York City and neighboring counties in New Jersey were the only places comparable to Dade County in terms of jitney service. Because New Jersey Transit's problems with jitneys are of recent origin, New York City was the only city identified as a candidate for this task.

The New York City Transit Authority (NYCTA), in conjunction with other city and state agencies, recently conducted and analyzed intensive jitney enforcement efforts in Brooklyn and Queens. In addition, state and city legislation has shifted responsibilities for and added strong provisions in support of enforcement efforts. CUTR arranged for on-site interviews and observation of jitney operations.

This paper documents the findings with regard to jitney enforcement efforts in New York City and their applicability to Dade County. The issues are remarkably similar in both places, although the origins and evolution of jitney service are different. Information is drawn from documents prepared by NYCTA and its parent organization, the Metropolitan Transportation Authority (MTA), and from the interviews conducted in New York. The interviewees included representatives from NYCTA and MTA, the Amalgamated Transit Union in the borough of Queens, the offices of the mayor and of a congressional representative, the New York City Council's Transportation Committee, transit and city police, a major legal van operator in Queens, and a consultant who has worked extensively in support of the jitneys.

The first section of this paper presents a brief description of the history of jitney service in New York City and reports the changing legal environment for jitney regulation. The following two sections describe the conduct and results of two enforcement efforts undertaken in 1992, one along Flatbush Avenue in Brooklyn and the other in the Jamaica area of Queens. The results of the interviews and the perspectives of the various parties are then presented. Conclusions and implications are discussed in the final section.

One difference between Dade County and New York City is in terminology. "Jitney" is used in Dade County, whereas in New York these vehicles are referred to as "vans." The Dade County usage is applied here for the sake of consistency.

JITNEYS IN NEW YORK CITY

Unlike Dade County, New York City does not have a long history of legal jitneys. The first recent instance of unauthorized jitney

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operation was noted in southeast Queens during the 1980 transit strike, when individuals operating private vehicles began to provide local service and feeder transportation to the Long Island Rail Road station in Jamaica. These individuals continued in illegal operation as feeders to the subway system after the strike was settled and regular bus service was restored. Private cars were used at first, but 14-seat vans quickly emerged as the vehicle of choice for jitney service. Recently, an increasing number of 20-seat vans have been observed in operation. The jitneys thrived along busy bus routes with peak frequencies of 12, 15, and even 20 buses per hour, because of the high numbers of people congregated at bus stops along these routes.

Jitney fares originally matched the fares charged on NYCTA buses. When bus fares have been increased, jitney fares have lagged behind for a time but usually have risen to match the new bus fares within 1 to 2 years.

Jitney operators generally did not observe any of the laws and regulations governing vehicles and drivers who carry passengers for hire. New York State had jurisdiction over vehicles of this size (larger than taxicabs but smaller than buses). Eventually, some of the larger jitney operators petitioned the New York State Department of Transportation (NYSDOT) for authorization to operate back and forth between the subway and certain neighborhoods. NYSDOT evaluated requests on a case-by-case basis and did grant legal authority to jitney operators who were able to show a demand for their services. The situation evolved to the point where legal and illegal jitneys operated with little constraint along the busiest NYCTA bus routes and along routes operated by surviving private bus companies (Green Bus and Jamaica Bus) in southeast Queens.

Enforcement efforts were sporadic, given a lack of resources and low awareness of the problems caused by jitney operations. During most of the 1980s, the primary enforcement effort consisted of a single New York City Police Department officer in the local precinct in Jamaica. In 1989 and 1990 enforcement sweeps consisting of a concentrated 1-day effort at a particular location became a standard practice. These sweeps resulted in a significant number of citations (interestingly, about 40 percent of the summonses issued are for unlicensed drivers), but their effectiveness was extremely limited.

The jitney problem was not confined to this area of Queens. Other feeder services sprang up in Brooklyn (along Flatbush Avenue and in Coney Island) and to a lesser extent in the Bronx. In Staten Island, the most physically isolated of the five boroughs that make up New York City, jitney operators applied for and received Interstate Commerce Commission authorization to operate commuter service to Manhattan via New Jersey. New York City distinguishes between feeder vans and commuter vans, but both operate in similar fashion. Estimates of the number of jitneys operating in New York City range from 2,400 (*1*) to 5,000.

A policy report prepared by MTA staff in January 1992 indicates that jitneys tend to proliferate in neighborhoods with high concentrations of Caribbean immigrants (*1*). Since jitneys are a commonplace form of transportation in Jamaica, Puerto Rico, Haiti, and other islands in the West Indies, immigrants from these places showed an immediate willingness to use jitneys. This cultural aspect regarding perceptions of public transportation service, particularly a familiarity with jitneys, appears to have been a necessary condition for the initial development of jitney service. The Dade County and New York City metropolitan areas have a much higher percentage of West Indian population, as indicated in Table 1. This might explain why jitneys have not emerged to any significant extent in urbanized areas other than New York and Dade County. It should be noted that after they are developed, jitney services attract a wider segment of the population in neighborhoods in which they operate.

The same MTA policy report addressed other issues surrounding jitney operation. The report suggested four options for managing jitney operations (*1*):

1. A vigorous enforcement effort, in conjunction with efforts to reduce the labor costs associated with NYCTA bus operation, to enhance bus service and to make fares more competitive;
2. An orderly withdrawal of NYCTA bus service from areas where jitneys operate at a competitive advantage;
3. A withdrawal of NYCTA express bus service, with no change in local service; and
4. A broad policy change to centralize bus transportation planning and the responsibilities of route franchising and contracting within MTA, with a resulting public-private network incorporating jitneys and including enforcement efforts.

The report recommended a further evaluation of these options and continued interim enforcement efforts. The MTA Board of Directors voted unanimously (with two abstentions) to continue enforcement efforts.

Recent legislative developments may result in stricter jitney enforcement efforts. The New York State Senate and Assembly passed enabling legislation during its 1992 session and amended this legislation during the 1993 session. The enabling legislation allows New York City to adopt a local law regulating the jitneys. The city enacted local legislation in December 1993 that transfers responsibility for jitney regulation and enforcement from the state to New York City. The enabling legislation mandates several strong provisions that have been included in the New York City law. These provisions include the following mandates:

1. Jitneys (termed "van services" in the legislation) must provide service on a prearranged basis only; street hails are not permitted.
2. Jitneys are not permitted to solicit, pick up, or discharge passengers at any point along a NYCTA or private fixed bus route. A grandfather clause in the 1993 amendment makes an exception for jitneys with prior authorization to serve certain areas in lower Manhattan.
3. Seizure of a vehicle by a police officer or deputized agent of the Taxi and Limousine Commission (TLC, which will be charged with enforcement of jitney regulations) is permitted if there is reasonable cause to believe that it is being operated as a jitney without a license. TLC must hold a hearing to adjudicate the violation within 5 days of seizure.
4. The jitney may be released before the hearing if the jitney owner has no previous record of illegal operation. The owner must post a bond, of sufficient value to cover the maximum penalties possible and reasonable costs for removal and storage, in order to obtain release. If the owner does not reclaim the vehicle before the hearing and is subsequently found guilty, the vehicle can be released only after all penalties and costs are paid. The maximum fine for a first violation is $1,000.
5. For a second violation, the jitney may be held until adjudication (that is, for up to 5 days). The owner, if found guilty a second time, then must pay all applicable penalties and costs in

TABLE 1 Percentage of Metropolitan Area Populations of West Indian First Ancestry (7)

Metropolitan Area	Population	Population of West Indian First Ancestry	Percentage
Miami, FL	1,937,094	105,477	5.45%
New York, NY	8,546,846	403,458	4.72%
Newark, NJ	1,824,321	29,727	1.63%
Boston, MA	2,870,650	40,363	1.41%
Washington, DC	3,923,574	32,234	0.82%
Philadelphia, PA	4,856,881	16,650	0.34%
Baltimore, MD	2,382,172	7,504	0.32%
Houston, TX	3,301,937	9,551	0.29%
Los Angeles, CA	8,863,164	25,295	0.29%
Atlanta, GA	2,833,511	8,291	0.29%
Chicago, IL	6,069,974	13,529	0.22%
Oakland, CA	2,082,914	3,388	0.16%
Dallas, TX	2,553,362	3,506	0.14%
Cleveland, OH	1,831,122	2,159	0.12%
San Francisco, CA	1,603,678	1,733	0.11%
Honolulu, HI	836,231	927	0.11%
San Jose, CA	1,497,577	1,483	0.10%
Detroit, MI	4,382,299	3,920	0.09%
Seattle, WA	1,972,961	1,349	0.07%
Minneapolis, MN	2,464,124	1,253	0.05%
Pittsburgh, PA	2,056,705	1,102	0.05%
Denver, CO	1,622,980	860	0.05%
St. Louis, MO	2,444,099	976	0.04%
Portland, OR	1,239,842	530	0.04%

order to recover the vehicle. Even then, the city can choose to institute forfeiture procedures, as noted later. The maximum fine for a second or subsequent violation within a 5-year period is $2,500.

6. Upon a second conviction or for a third violation within 5 years for operation of a jitney without authorization, the vehicle may be seized and forfeited to the city if it is found that the owner was aware of the vehicle's illegal use and did not take reasonable steps to prevent such use.

7. The city may request that the New York State Department of Motor Vehicles (DMV) place a block (based on the vehicle identification number) on the reregistration of any vehicle with a violation for illegal operation as a jitney. DMV currently can block reregistration at its discretion; the recent legislation would make such a block mandatory upon request of the city.

The New York City Mayor's Office for Transportation and the New York City Council were attempting to craft legislation at the time of the interviews. As mentioned earlier, the legislation passed (by a 41 to 4 vote) and was signed by Mayor David Dinkins in December 1993.

In 1990 an interagency task force on jitneys was established to consider different approaches to combat the problem. Two major enforcement efforts were undertaken in 1992 and are described in the following sections. The first was along the Flatbush Avenue corridor in Brooklyn, and the second was first focused on Jamaica Center and later extended more widely in southeast Queens.

Jitney Enforcement Efforts

Brooklyn

The Flatbush Avenue corridor in Brooklyn was selected as the first target for a controlled and concentrated enforcement effort. NYCTA used the strategy of targeting one specific location at a time in its graffiti eradication program in the 1980s. A major traffic corridor, Flatbush Avenue had experienced a large-scale influx of jitneys. A high proportion of these jitneys were illegal and, judging by their appearance, unsafe. The overall purpose of this experiment was to determine the ridership and revenue impacts, resource requirements, and cost-effectiveness of concentrated enforcement.

The Flatbush Avenue corridor extends for 7 mi from downtown Brooklyn to Kings Plaza, the only suburban-style shopping mall in Brooklyn. NYCTA operates the B41 bus route in the corridor. Ridership on the B41 is the heaviest of any route in Brooklyn, with an average weekday ridership of 35,000 (*2*). The Brooklyn central business district and Kings Plaza are major trip generators at opposite ends of the route, resulting in strong ridership demand in both directions for most of the day. On its outer portion, the B41 also functions as a feeder route to the No. 2 rapid transit line, which terminates at Flatbush and Nostrand Avenues.

Prior enforcement actions had been sporadic and limited, as noted earlier. The Flatbush Avenue experiment was designed to be a 6-week effort (March 9 through April 19, 1992) for 16 hr/day on weekdays and 8.5 hr/day on weekends. The Transit Police Surface Crime Unit assigned approximately 20 officers and 3 supervisors on weekdays, with an additional 2 to 4 police officers assigned by a local precinct of the New York City Police Department. Towing resources and storage space were provided by the New York City Department of Transportation (NYCDOT).

An important facet of this effort was an extensive public outreach program aimed at community officials, bus riders, and van operators. All elected and community officials were informed of the upcoming enforcement and its purposes in advance. NYCTA posted service announcements in all buses, printed and distributed brochures describing the enforcement effort, and assigned personnel to high-volume locations to provide customer assistance during the 6 weeks. NYCTA also distributed flyers to van operators in the corridor before the enforcement effort, advising them of the regulations that would be strictly enforced. This preenforcement activity was important in gaining public support for the enforcement actions.

As a final step in the preenforcement activity, plans were drawn up to provide additional service on the B41 route to accommodate expected increases in bus ridership. Eight extra buses were added (four in the morning peak and four in the evening peak) during the first week (*2*). By the middle of the experiment, an additional five buses were placed in service during the morning peak, for a total of 13 additional runs. These additional runs were originally done as extra service with overtime pay but were incorporated into the regular B41 schedule at the next opportunity, thus reducing the costs.

The ridership and revenue results of the concentrated enforcement were impressive. In areas with jitney competition, the riders most likely to stay with bus service are those who are eligible for discounted fares and those who are transferring between routes. It was not surprising, therefore, that the largest ridership increases were experienced among full-fare riders. Weekday ridership on the B41 route increased by 27 percent, from 35,700 to 45,200, while weekday full-fare ridership increased by 51 percent, from 14,700 to 22,150 (*2*). Average weekly revenue increased by 42 percent during the same 6-week period. Observed jitney trips declined from a preenforcement estimate of 2,350 daily weekday trips in January to an observed estimate of 726 trips in March, a decrease of 69 percent (*2*). The increase in B41 ridership was larger than the observed decrease in the number of jitney trips, suggesting that bus riders were attracted from other options or that jitney trips were undercounted. Nearly 2,500 universal summonses (for traffic violations) were issued to the jitneys, along with nearly 500 notices of violation (for illegal operation of vans).

A cost/benefit assessment was performed using annualized revenues and costs (*2*). The annualized increase in NYCTA revenue resulting from ridership increases was estimated at $2.82 million, with an annualized increase in cost of $1.90 million ($1.1 million in enforcement, $0.8 million in increased service). The resulting net benefit is $920,000 a year. Note that this figure does not include any projected revenue obtained from summonses or notices of violation. During the 6 weeks of sustained enforcement, revenue from these sources totaled $187,000.

At the end of the experiment in mid-April 1992, there was an increase in jitney activity along Flatbush Avenue and a concomitant decline in B41 ridership and revenue. By September 1992, about half of the gains in ridership and revenue had been lost as enforcement efforts were directed elsewhere in the city. To maintain and increase ridership, limited-stop service was instituted on the B41 route in September 1992. Designated B41 limited buses stop only at major destinations and transfer points, resulting in a travel time savings of between 10 and 15 min. Increased enforcement efforts to keep clear a dedicated bus-only lane in downtown Brooklyn were also undertaken at this time. Average daily revenue has remained stable since the implementation of limited-stop service, at 20 percent above the preenforcement level (*3*). Customer satisfaction is high, with 63 percent reporting that service has improved (*4*). A notable percentage of B41 riders (22 percent at limited stops, 37 percent at local stops) indicated that they formerly used vans or car services for their trips (*4*). Thus, the limited-stop service improvement has helped to retain the increased ridership resulting from the jitney enforcement actions.

The conclusion drawn from the Flatbush Avenue experiment is that sustained jitney enforcement in conjunction with service improvements is a cost-effective action. The appropriate level and duration of effective enforcement has not been conclusively determined. Personnel from the Surface Crime Unit of the New York Transit Police have indicated that a sustained effort of 10 weeks, followed by up to 3 months of enforcement at roughly half the level of the concentrated enforcement and then routine enforcement patrols would be most effective. Whatever the optimal level, it is clear that the combination of a sustained enforcement effort and bus service improvements can combat jitneys and reverse the trend of declining ridership and revenue on bus routes affected by jitney competition.

Jamaica, Queens

Jamaica is the hub of feeder bus routes extending throughout eastern and southeastern Queens. When jitney service first began in this area in 1980, all NYCTA routes fed the Hillside Avenue subway at either 179th or 169th Streets. In 1988 the Archer Avenue rapid transit line was completed, and NYCTA buses from southeast Queens entering Jamaica via the Merrick Boulevard corridor were rerouted to serve the new Jamaica Center station. Legal and illegal jitneys soon followed the buses to Archer Avenue.

Immediately after the station was opened, the six bus routes in the Merrick Boulevard corridor experienced ridership increases of 13 percent, but the jitneys soon began to siphon riders (*5*). Of the six bus routes entering Jamaica via the Merrick Boulevard corridor, three were particularly affected by jitney competition. These three routes were generally the busiest routes and operated along major commercial streets. The first enforcement sweeps focused on Jamaica Center but proved to be ineffective beyond the day on which they occurred.

The effect of the jitneys on the Merrick Boulevard corridor buses was compounded in fall 1990 by an ill-advised one-way pair street conversion on Jamaica and Archer Avenues. The one-way pair added approximately 5 min to the travel time of every evening peak-period bus leaving Jamaica Center, because of its unusual configuration requiring a detour north to Jamaica Avenue (*6*). On the other hand, the jitneys' travel time was reduced by the one-way pair because of their loading locations in Jamaica Center. This accelerated the decline in ridership on the six routes. The city abandoned the one-way pair, and NYCTA restored its original routing for the six routes leaving Jamaica Center in August 1993.

Southeast Queens is a two-fare zone, since there are no bus-to-subway transfers in New York. A reduced-fare initiative was undertaken in October 1992 in an attempt to reclaim lost market share on the Merrick Boulevard corridor buses. Instead of the one-way fare of $1.25, a round-trip fare of $1.50 was offered on the six bus routes. Riders would pay $1.50 on their way to Jamaica and receive a ticket for the return trip. Thus, a rider would experience a daily fare decrease from $2.50 to $1.50 for a bus only trip or from $5.00 to $4.00 for a bus and subway trip. The Merrick Boulevard corridor routes were not operating at full capacity; thus, service adjustments required in conjunction with this initiative were minimal. Daily ridership increased on the six routes by 2,500 or 8 percent. Revenue had been expected to fall, but it remained constant (*3*).

In December 1992 a concentrated enforcement effort began in Jamaica Center under the leadership of the New York City Police Department, with the assistance of the New York City Transit Police's Surface Crime Unit, NYSDOT Motor Carrier Investigators, the TLC, Long Island Rail Road police, and NYCDOT. Daily ridership on the Merrick Boulevard corridor routes increased by an additional 3,000 riders for a total ridership increase of 5,500, and revenue rose by $3,000 (*3*).

A second phase of the enforcement took place from mid-February through the end of June 1993 and was focused in the morning hours in the residential neighborhoods served by the major Merrick Boulevard corridor routes. This resulted in an additional 2,500 daily riders, for a total ridership increase from November to March of 8,000 or 26 percent. The total daily revenue increase was $5,500 (*3*).

Limited-stop service had already been instituted in the peak direction during the peak periods on the three routes most affected by jitneys in southeast Queens. In January 1993 the evening limited-stop buses were rerouted to avoid the circuitous one-way pair, with a travel time savings of approximately 5 min. This service enhancement contributed to the increase in ridership.

The Jamaica experiment suggests that sustained enforcement combined with a reduced-fare initiative can be a successful tool to increase bus ridership and revenue. The two private bus companies operating in Jamaica have experienced similar revenue increases during this enforcement. NYCTA's Queens Surface Division also reports a significant reduction in accidents during periods of intensive jitney enforcement. As in Brooklyn, a key element is the combination of intensive enforcement with either a service improvement or a fare reduction.

New York City Jitney Perspectives

Interviews were conducted with political, transit, jitney, police, and union representatives in New York City to gain a fuller understanding of the issues surrounding the jitneys and of possible solutions. This section reports the wide range of perspectives, as revealed in the interviews.

Political Perspective

Although some New York politicians are firmly on one side or the other of the jitney issue, most are hoping to find some way for jitneys and buses to coexist. Integration of the jitneys into the public transportation system is the long-term goal, although there are various opinions on how this will be accomplished. Immediate concerns include safety, reliability, efficiency, and fairness. The safety issue is paramount: there is a clear recognition that illegal jitneys are frequently uninsured, uninspected and operated by drivers with no license or with a suspended license.

On the other hand, it is recognized that the jitneys are here to stay and that a draconian approach will not work. The need for consistent enforcement is acknowledged along with the need for a path for jitney operators with good safety records to become legal. The jitneys are perceived as convenient, fast, inexpensive, and desirable for many riders. The employment opportunities offered to the communities in which vans operate are recognized by politicians. Increased revenue opportunities for the city arising from the licensing of jitney operators are also perceived.

Constituents are reported split on the jitney issue: users are very supportive, nonusers (especially senior citizens who are not granted discounts on the jitneys and residents of streets used by jitneys) are opposed, sometimes vehemently so. This split in public opinion adds to the difficulty in devising a workable solution. The political perspective is that in the long run, jitneys must somehow be integrated into the transit system within a framework provided by the city. The transit unions are seen as a major stumbling block, but there is a sense that jitney competition may spur changes in antiquated work rules.

Attempts to craft a local ordinance in accordance with the enabling state legislation have encountered various obstacles. Legal jitney operators are extremely concerned over the prohibition of street hails along bus routes as well as the requirement for prearrangement of jitney services. NYCTA is strongly supporting the block on reregistration of any vehicle with a series of violations for illegal operation as a jitney, but the city is worried that innocent purchasers might unknowingly buy a vehicle subject to a reregistration block. NYCTA is also requesting that jitney authorization be required for a specific geographic area and granted only if there is a finding of need. The city has little desire to be placed in the position of determining how much transportation is "enough" and argues that a needs analysis for every jitney application would waste money that could be spent on enforcement. The city hopes to set up a system centered on base operations from a central dispatching location for each jitney operator, similar in many respects to private taxicab services.

The political perspective may be characterized as squarely in the middle on the jitney issue. Problems with safety are acknowledged, but the jitneys are perceived as meeting a real transportation need in the communities in which they operate. Extreme options (defined as "enforcing the vans into the sea" or ignoring the problems) are rejected, but ways in which the jitneys can be integrated are still being sought. Possibilities include the licensing of jitneys to serve areas where there is little or no existing transit service, but this is difficult in a city with such an extensive bus network.

Transit Perspective

There is a range of perspectives within NYCTA and MTA concerning the jitney problem. At one end of the spectrum are those involved with broad policy-making decisions; at the other end are those directly responsible for service provision and enforcement strategies. Concerns about safety issues and revenue and ridership losses are shared across the entire spectrum, as is support for continued enforcement efforts.

In general, transit policy makers recognize the eventual need for some sort of service coordination with the jitneys. They understand, but do not necessarily agree with, the perception on the part of outsiders that jitneys are introducing competition into a system bloated by artificial work rules and other constraints. The market niche established by the jitneys is acknowledged, as are the differences under certain circumstances in service quality that makes that niche possible. A general policy that allows legal jitneys to operate in coordination with NYCTA buses, with sufficient controls in place to ensure that they stay within the limits of their authorization, is the ultimate goal. Transfer of regulatory power from the state to the city is an important step toward this goal. Another step suggested is the transfer of the power to franchise routes to the MTA. MTA has the power to contract routes, but the contracting of existing service is subject to union negotiation due to the state's Taylor Law (which governs the rights and responsibilities of public-sector unions) and Section 13(c) of the UMTA Act of 1964.

Transit policy makers see the possibility of a long-term role for jitneys in a coordinated public transportation system, but there is a keen awareness of short-term concerns. The enforcement efforts in Brooklyn and Queens are viewed as successful and necessary to establish control in major transit corridors. Community support of these efforts has been a key factor in their success. Great care has been taken in crafting these enforcement efforts to be sensitive to community concerns and to avoid negative public response. The results of market research indicating both concerns over jitney safety and insurance and the importance of service quality have been incorporated into decisions on enforcement strategies.

There is also strong concern regarding the city's approach to the state enabling legislation. Both MTA and NYCTA view the definition of the area to be served by licensed jitneys and an assessment of need for service in that area as vital elements of a long-term jitney policy. The city's unwillingness to address the issue of need is seen as contrary to the spirit of the enabling legislation. There is a fear that jitneys will be treated as another form of for-hire private transportation, not as an element of (and potential competitor with) the public transportation network.

Notwithstanding the immediate concerns, transit policy makers envision a long-term accommodation with authorized and regulated jitneys. The exact mechanism for integrating the jitneys is not yet defined; the most feasible appears to be identifying separate markets for the jitneys and the buses. This may involve new service or a contracting of existing low-volume routes that can be better served by smaller vehicles. Other service options include "peak-shaving," or dispatching jitneys in the peak periods to supplement bus service, and contracting service to jitneys at certain times of day (e.g., after 9:00 p.m.).

Transit personnel who are more closely involved with service provision and enforcement efforts are considerably less sanguine about the possibility of integrating jitneys into the existing transit network. The view at ground level is that there is a huge gap between philosophy and reality on this issue. Those interviewed cited vehicle and traffic safety, the prevalence of suspended drivers licenses, jitney participation in an underground economy, and new requirements mandated by the Americans with Disabilities Act as important concerns. The public accountability of the jitneys under any system, current or proposed, was identified as a major issue. The prevailing view of the transit operating personnel was that the legal jitneys used their authorization as a cloak to operate wherever and however they please. The possibility of jitneys and buses serving the same corridor was dismissed as absolutely unworkable. The enforcement efforts in Brooklyn and Queens were viewed as a major accomplishment, but there was a clear understanding that enforcement alone, without service improvements or fare initiatives, would not succeed. There was obviously little support for integration of the jitneys among this group.

Jitney Perspective

Representatives of legal jitney operators, not surprisingly, take exception to being criticized along with the illegal jitneys. The legal operators generally have supported and cooperated with enforcement actions targeted at those without authorization, since the illegals reduce their ridership as well as that of the transit authority. The jitney operators argue that enforcement by ticketing has been proven to be ineffective, since fines are merely a cost of doing business, and that enforcement must be concentrated to be effective. Legal operators support the forfeiture provision in the state enabling legislation as the key to eliminating illegal jitneys, although they suggest that they be allowed to absorb those who wish to be legalized.

Legal jitney owners are strongly opposed to the provision that jitneys not be permitted to pick up passengers anywhere along bus routes, because buses travel on all major arteries in their service areas. Detours to side streets are inconvenient to their riders. They suggest that their market has grown to such an extent that they should be allowed to operate on streets with bus routes on at least a trial basis, although they are willing to abide by regulations that prohibit picking up and discharging passengers at bus stops. Legal jitneys in Queens now carry signs in their windows indicating that they will not stop at bus stops, and owners have indicated that they will take action against drivers who violate this policy. The legals also argue that they must be permitted to discharge passengers along a bus route (except in a bus stop) if the passenger so wishes.

The legal jitneys argue that they provide quick, safe, comfortable, and cost-effective transportation that complements existing NYCTA bus service. They also point to the employment opportunities created by the jitneys, not just for drivers but in ancillary services such as repair shops and car washes. The legal operators in Queens want to be left alone in Jamaica Center, where there is an informally designated jitney loading area separate from the bus stops, and to be permitted to drop off passengers along bus routes. They willingly support a cap on the number of jitneys permitted per operator, since this cap is good for business, although they would prefer to be allowed a defined annual increase.

Jitney supporters have advanced a more theoretical argument regarding the inability of a public agency to regulate quality and volume of service simultaneously. Following this line of reasoning, an agency such as NYCTA must give up either quality or volume in attempting to provide service in an area of high demand. In either case, a market is created for an alternative such as the jitneys. Supporters dismiss protransit arguments that the jitneys undermine the considerable public investment in transit facilities by claiming that sunken costs are irrelevant.

The legal jitney operators view buses as inflexible and inefficient and claim that competition from the jitneys has forced NYCTA to become more efficient and to improve customer service. They profess to be unaffected by the fare initiative in Queens and deny that it has been successful to any great extent. Although they are willing to cooperate with NYCTA in enforcement activities targeted at illegal jitneys, the legal operators claim that they must be allowed some leeway in order to satisfy their customers. The legal jitneys flatly reject charges that they have become less vigilant with regard to safety and operator qualifications as they have increased in size.

Police Perspective

As the agents carrying out any enforcement strategy, police officers bring a unique perspective to the jitney problem. The police experience with jitney enforcement has emphasized the need for a concentrated, coordinated effort. Illegal jitney operators must be convinced that the enforcement is serious. At the same time, sufficient resources must be allocated to any enforcement effort, as was the case in the Flatbush Avenue and Jamaica Center experiments. This commitment is particularly necessary in a multiagency enforcement effort, since each agency has competing priorities affecting its assignment of manpower.

In the New York City experiments, the Transit Police Surface Crime Unit and the New York City Police Department had primary responsibility for enforcement. They were supported by NYSDOT Motor Carrier Investigators, TLC personnel, Long Island Rail Road officers, and NYCDOT towing resources. As noted earlier, one purpose of these enforcement experiments was to determine the optimal length of an action, and the duration of the effects of enforcement. The general consensus was that the most concentrated effort should last for approximately 10 weeks and then be lessened over 3 months, followed by routine patrols.

One major concern voiced by the police was the willingness of the courts to support the enforcement effort. The courts are generally viewed as lenient and unaware of the issues involved in jitney enforcement. The TLC, which will be charged with responsibility for jitney enforcement, has its own adjudicatory process, which the police hope will bring greater understanding and support for enforcement.

Police officials indicate that the legal jitney operators do cooperate with enforcement efforts, particularly by providing the names of drivers who are no longer with the company. Some legal operators are caught in enforcement efforts with suspended drivers' licenses, inappropriate registration or lack of insurance. Enforcement efforts, however, are generally oriented toward illegal jitneys, which pose a greater safety hazard.

Police officials charged with carrying out jitney enforcement are most concerned with the level of resources dedicated to the effort (in terms of both the number of officers and agents and the support facilities such as tow trucks and vehicle lots) and the effectiveness of the adjudication process. Their orientation is primarily public safety, but there is a sense that the revenue impacts of enforcement may be a greater incentive for the city to commit to a serious enforcement program.

Union Perspective

The transit union shares many of the viewpoints of the transit officials involved with service provision with regard to the jitneys. The union representatives view sustained enforcement as the key, in conjunction with service improvements. The union also shares the perception that authorization is a smokescreen for the legal jitneys to operate as they please. The idea of ultimately reaching an accommodation with the jitneys is understood, but provision for off-route jitney operation on a prearranged basis is seen as the only acceptable way to integrate the jitneys. The union opposes the concept of contracting existing routes or service to the jitneys.

From the union's perspective, NYCTA management made a mistake by cutting bus service in the 1980s in response to ridership decreases caused by the jitneys. At present, however, there is a strong spirit of cooperation between labor and management with regard to jitney issues. NYCTA officials readily acknowledge that the unions are very aware of the need to compete with the jitneys and to improve the quality of service. This cooperation brings benefits to both parties in that it provides the beginnings of a framework for the discussion and possible resolution of divisive issues. This labor-management dynamic is not clearly understood by those who perceive the unions as the major stumbling block to the ultimate resolution of the jitney issue.

CONCLUSIONS AND IMPLICATIONS

Several conclusions may be drawn from New York's recent experience with jitney enforcement. These conclusions have clear implications for future efforts.

1. *Enforcement works, in conjunction with service improvements or fare initiatives.* The Flatbush Avenue experiment in Brooklyn provides the best documentation that a concentrated, sustained enforcement effort, implemented in conjunction with bus service improvements, can be a cost-effective means of increasing transit ridership and revenue. Although the increases experienced during the period of concentrated enforcement were not sustained, revenue on the B41 bus route 1 year after the enforcement and service changes showed an increase of 20 percent compared to preenforcement levels. The optimal extent and duration of enforcement actions have yet to be determined, but the intensive 6-week effort has yielded clear results.

The combination of enforcement and fare initiative in Jamaica, Queens, was also successful in increasing transit ridership and revenue. Both the police and transit operating officials noted an improvement in safety during the enforcement period.

2. *Integration of jitneys into the public transportation network is a desirable goal.* All parties in New York agree that the jitneys are here to stay and that it makes sense to integrate them into the system. The major problem lies in defining what exactly is meant by integration and how this integration is to take place. The most promising method is to authorize the jitneys to serve areas or neighborhoods currently not served or underserved by existing bus routes. In New York, these areas are not easily defined. In Dade County, the role of the jitneys in serving areas damaged by Hurricane Andrew strengthens the case for integrating them into the transit system. Dade County may have an easier time defining areas appropriate for jitney service due to continued growth in the county.

3. *Even with integration, the need for enforcement will remain.* Franchising legal jitneys to serve defined areas does not solve the problems caused by illegally operated jitneys. There will be a continued need for enforcement on the bus routes and on the new jitney routes. In addition, the legal jitneys must be monitored to ensure that their operation conforms to their franchise authority.

4. *Cooperation between the union and the transit agency is necessary in resolving the jitney issues.* The agency and the union are both affected by competition from the jitneys. Any solution must address the concerns of both parties in order to have a chance of success.

The large-scale emergence of jitneys has challenged the transit agencies in Dade County and New York City to examine policies and service issues more closely. Ultimately, the jitney operators may prove to be correct in their assertion that they have forced the public transportation agencies to be more responsive to customer needs. Enforcement efforts can play a significant and cost-effective role in addressing the safety problems associated with illegal (and sometimes with legal) jitney operation, while a means of cooperation between bus and jitney is sought.

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PART 6

Transit Security

Maximization of Transit Security Through Effective Use of Procedures

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FTA's safety and security program goal is to achieve the highest practical level of safety in all modes of transit. To protect passengers, employees, revenue, and property, all transit systems are encouraged to identify, evaluate, and adopt security procedures that are most efficient and effective in local practice. Both proactive and response procedures should be included along with methodologies for reviewing their effectiveness. The materials in the *Transit Security Procedures Guide*, which was produced by Ketron while under contract to the Volpe National Transportation Systems Center, are summarized. The guide was designed to make systems aware of the procedures used across the country by transit security specialists. The summary includes information on applying the system's approach to transit security planning and implementation, proactive materials for the prevention of security incidents, procedures for immediate and follow-up response to security incidents, and a specific evaluation methodology for security problems including crimes against passengers, crimes against the transit system, crimes against the public (hostages, hijacking, bomb threats), and general issues. The methodology includes information on the most important attributes of each security problem: severity, frequency, type, areas of effect, when, locations, contributing factors, solutions and approaches, personnel costs, facility and equipment cost, effectiveness, and application.

The security of a transit system is an integral part of the service that it provides to its riders. Passengers perceive it as the responsibility of the system to ensure that they are safe. If passengers are not safe, the system is failing its responsibility. Passenger perceptions affect system ridership and revenue. The system is also responsible for the security of its own personnel, facilities, and equipment.

This paper summarizes a product developed by Ketron for the Volpe National Transportation Systems Center and FTA entitled *Transit Security Procedures Guide.* It represents a compilation of available materials into a single, usable guide that incorporates the necessary information for planning and improving transit security. The information is designed to be used by transit planners, security personnel, and managers in the development of their plans, procedures, and capital programs. A central tenet is to encourage systems to take a proactive systemwide approach to security.

The systems approach includes examining all aspects of the system and evaluating potential security risks. It involves planning for security before the incident rather than reacting. This approach has several advantages. First, it allows an examination of how all aspects of the system interact to affect security, including personnel, procedures, equipment, communication, and passengers. A second advantage is that security risks and the measures needed to mitigate them can be identified before an actual security problem develops. Preventative measures can be applied and the dangers, problems, and resulting costs can be avoided. The third advantage is that security measures can be implemented in a cost-effective manner if they are incorporated in the planning stages of facilities, personnel training, and equipment purchases.

Systems need to reduce risks to passengers, personnel, and equipment. Planning and anticipating security risks can limit the number of incidents and reduce their consequences. Reacting to a security breach is costly. For example, if fares are stolen, revenue is lost. Even if the perpetrator is found, recovery of the lost fares may not be possible. Without the installation of effective countermeasures, such as observation cameras, alarms, and security procedures, there may not be a means for locating the perpetrator at all.

A breach in security can also have an effect on the morale of employees, who will feel more at risk. In addition, there can be a negative affect on the perceptions of passengers, who will feel that they are not adequately protected. These costs can be reduced if countermeasures are in place, such as observation of the incident to aid in identifying the perpetrator, procedures for raising an alarm for when the perpetrator leaves the vehicle or the facility, storage of some of the fares in inaccessible safes, and existing procedures for apprehending the offender.

Security planning involves identifying possible areas of security threats, assessing the magnitude of the threats and the vulnerabilities of the system to them, planning for the resolution of the threat, and following up the security breach with an evaluation of procedures, plans, and policies to address any errors and implement necessary changes.

Each system's security program must address its particular needs and the particular threats that can be identified during security planning. Each system is different and will be able to identify particular areas of risk. Each system will also have differing levels of resources to address those risks. The procedures discussed here provide the information necessary to rank system needs and to allocate resources effectively.

Preventing security incidents is a major topic. This paper describes methods for developing preventative procedures and discusses staffing, equipment, features, and hardware that can address the security risks that systems face. A systems approach is used to examine preventative measures in all aspects of the system, from the point of view of the passenger, transit personnel, and the risks to the equipment and facilities. All security aspects of the system are interrelated. Staffing of facilities has an effect on overall security, as does the design of facilities. Choices of equipment and security systems are affected by the types of facilities and the

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level of staffing. At the same time, equipment choices can affect staffing levels and the types of design features incorporated into facilities. Information necessary to make informed choices and to be certain that the choices made are addressing the particular security needs of the system are presented.

The second major area discusses security responses and offers information on the actions that systems should take if there is an incident. Actions include immediate response, communication, follow-up, and reporting. Each needs to be defined and described in the passenger, vehicle, and facility system security program plan. Transit personnel need to know what response is expected of them when a security incident occurs, what to do to help prevent an incident from escalating, and how to minimize the effects of the incident on passengers and facilities. Follow-up and reporting are also important for evaluating the causes of security incidents and improving methods for preventing them. Effective follow-up and reporting allow the system to learn from incidents and to prevent them in the future. Systems can use this information to develop their necessary response procedures.

The third major section addresses special security problems. It considers a variety of problems experienced by transit, including crimes, misdemeanors, and annoyances, through the use of an evaluation format. Security problems can be difficult to solve. They often require ongoing procedures and can require urgent attention. The format includes the types of procedures that can be successful in different types of systems, special security problems from the perspective of potential solutions, and solutions as to their cost and effectiveness and the type of application necessary for a successful approach.

This paper is a summary of the full *Transit Security Procedures Guide*. Consequently, the specificity of the information presented is lower than in the full document. However, significant information is conveyed. Positive results can be achieved by following the suggested program; the number of security incidents should be able to be reduced and the consequences of the actual realized security incidents should be minimized.

PREVENTION OF SECURITY INCIDENTS

Every system should have a security plan and security director. The number of system employees, whose primary function is security, will vary depending on the size of the system and the approach to security staffing. However, security is the responsibility of every employee. This section discusses the system's concerns and alternatives in security with regard to staffing. Details on the considerations necessary for a complete staff of security officers are provided, as well as discussion of the roles of personnel whose primary function is not usually security but who do play a vital role: operators, clerks, and other staff.

The section concludes with a discussion of coordination with local police departments—an extremely important element of all security programs, regardless of the size or makeup of the system. The materials in this section will not dictate what type or level of staffing is best for all systems. Presented here are the alternatives. The security department referred to throughout may be a staff of several thousand transit police and support staff, or a single security, safety, and training officer, depending on the needs of the system.

Persons responsible for patrolling buses, guarding facilities, and responding to incidents may come from a variety of sources, including

- Local police (including state police in rural areas),
- Local police with special transit units,
- Contract police and security services,
- Transit police, or
- Some combination of the preceding.

Each of these approaches has merit.

All systems rely on local police forces to some extent. Smaller systems may rely exclusively on local forces. This arrangement is entirely appropriate if the security needs of the system are being met. Reliance on local police may be the best arrangement if the jurisdiction of the local force includes all or most of the transit service area.

If the system relies on local police, it would call the police to respond to any serious violation. Minor security incidents would be handled by in-house security staff or an operational supervisor. The security department would be primarily administrative and operational. The system may employ staff to identify problem spots to keep the local authorities informed. Although the system might additionally employ patrol guards, the rest of the in-house security staff would commonly be supervisors, station attendants, and spotters. The tasks of in-house security staff might also include locking up, inspecting the facility, reporting incidents, and providing a human presence.

Some systems rely on a special division of the local police department to provide policing services. The system can work out arrangements with local authorities for qualifications required for the transit unit staff. Typically the special transit team is a respectable if not elite assignment. The system may provide a great deal of orientation to these officers and involve them in operator training to help officers understand how transit operations occur. Special transit units often do not provide services that satisfy all the security needs of the transit system. Other security staff may watch facilities at night, guard revenue transfers, and perform administrative functions.

This type of arrangement represents a compromise between a separate transit police force and complete reliance on a police force that provides general services to a large area. The special unit has complete familiarity with the system and ongoing security problems but can draw on the same support resources as the local forces. Complications of transit security coordination with local forces are avoided because the officers are working through local forces. Additional manpower can be easily brought in as needed, drawing from the rest of the local force.

To establish a greater degree of control and to avoid the difficulties of administering a full staff, some systems contract for security services. By hiring the services of a number of officers, from a single firm or police force, the system can detail through the contract the exact requirements of the services. In some cases the system and security company together establish a pool of individuals from which to draw.

The security forces must report to at least one person in the system, although it is possible to contract out for both the staff and management of the security force. An individual or office within the system, however, would have to monitor the performance of the contractor and provide guidance and expectations.

Security officers contracted from private firms will not have full police powers. As security guards they may make citizen's arrests, detain individuals, and provide a uniformed presence and a rapid response, but they cannot make arrests and issue citations.

Transit systems with transit police forces require full police powers if the security staff is to be effective. Although security guards can deter less serious crime, police with full powers are needed to deter and respond to more violent crimes. In communities where transit crime is less often violent, police powers can do much to enhance the effectiveness of the force, but they may not be necessary.

An in-house force of transit police allows the system to rely less heavily on local forces but cannot eliminate the need for cooperation. Reporting functions need to be shared, and local forces must provide backup for the transit police. Often the local forces are more widely distributed geographically and in some cases will be able to respond faster. Furthermore, local police facilities are generally relied on for booking and holding functions.

Since it is always necessary to rely on and cooperate with the local police to some extent, it is extremely important that transit security staff command the respect of local forces. In the case of a transit police force, the local force may have to approve its creation before full police powers can be granted on a permanent basis. This is commonly achieved by setting high training and employment standards. It is often both convenient and useful to use the same standards as local police forces, even using the same training sites and local academies. Respect for the experience and capabilities of transit police is greatly enhanced by drawing staff from the local force, especially to serve as top officials. Salary rates are often based on the rates paid to local officers.

The use of a dedicated transit police force is especially appropriate when the system services many jurisdictions. The complexity of coordinating jurisdictional services can be greatly reduced through the use of a staff with full police powers that is responsible throughout the many locations that the system serves.

Selection of the appropriate approach is primarily a function of the size of the system, the number of political jurisdictions in the service area, and the need for the forces to have full police powers. For example, as the size of the transit system increases from small to very large, the progression is usually local police, local police transit units, contracted police services, to transit police. The upward progression also is associated with jurisdictions. With only one jurisdiction local police can often handle security. As the number of jurisdictions multiplies, transit police are most effective. If police powers are required, then the local police transit unit or transit police options are best.

Prevention of security incidents is dependent on the personnel available to provide policing services. In addition to the security functions of the operations staff, transit systems often use a variety of security personnel including sworn officers, security guards, patrol guards, spotters, locksmiths, inspectors, and supervisors. Selection of an in-house solution to security requires the acquisition of appropriate personnel. In addition, it often requires a significant capital investment in support equipment. The prevention of security incidents often requires equipment such as guns, chemical mace/pepper, handcuffs, batons, radios, bullet-resistant vests, badges, helmets, keys, disorder gear, uniforms, and vehicles. These items of equipment are effective in responding to security incidents and have a definite, positive, proactive value to the deterrence of security problems as a result of their visual presence.

Identifying and hiring security staff should be based on a specific set of minimum qualifications such as the following to ensure a highly capable force:

- Age preference (minimum/maximum),
- Height and weight (proportional),
- Interviews with security personnel or character investigators,
- Physical agility and dexterity,
- Physical fitness,
- Previous police or security experience of 1 to 5 years,
- Previous transit experience,
- Psychological character issues,
- Recommendations,
- Record checks, and
- General knowledge or aptitude.

Minimum qualifications should also be used if security manpower is contracted.

Additional costs result from the need to train personnel before putting them into service and then regularly thereafter to maintain required levels of readiness. Training should include

- Familiarization with existing and key procedures,
- Special weapons,
- Handling of the homeless,
- Public relations and assistance,
- Sensitivity training for victims, and
- Interjurisdictional coordination problems.

Security training should not be limited to security staff. All operations staff perform security-related functions, and their effective response and daily functions can be reinforced with refresher training and special courses. Ongoing training generally augments the morale of personnel, partly by providing a break from the regular routine and especially by extending the skills of individuals.

Coordination with local police departments is vital to the proper operation of any transit security program, especially emergency response. This coordination includes the sharing of information; agreement on roles, responsibility, and jurisdiction; setting up of communications; and cooperation during training, exercises, and operations.

Security can be an important factor in encouraging or discouraging rider use. Patrons' perceptions of security can be the major difference between transit users and nonusers. Transit security is generally perceived to be lower during off-peak hours because of the smaller numbers of people present and the effect of low light conditions. The perception of minimum transit security can keep off-peak ridership low during those hours. Improving off-peak security could do more to increase ridership at those times than operational measures such as increased frequency or destinations.

Individuals who have experienced a crime in the transit system, have witnessed a crime, or know someone who was a victim of a crime hold negative perceptions of transit security. However, most people's perceptions of security are unrelated to actual crime statistics. Passengers react to trash-strewn stations, evidence of vandalism, physical deterioration, graffiti, and other characteristics by perceiving a low level of passenger security.

In general, the public's perception of security depends on the visibility of protection efforts. Uniformed patrols are more effective than surveillance cameras. Surveillance cameras in plain view of passengers are more effective than hidden cameras. Surveillance cameras in conjunction with conspicuous booths where security personnel are watching monitors are more effective than security cameras alone. Good facility design features that ensure complete visibility also improve the perception of security. People will not feel secure if they must enter a station from a deserted alley or walk through a tunnel with turns, around which someone could be hiding. A bridge over tracks is more visible than an underground tunnel. Stairs can be left open rather than walled. Open fences improve visibility in comparison with walls. Facility corridors need to have as few turns and barriers as possible. Mirrors so that people can see around corners are also important.

Facility maintenance is another factor in increasing perceived security. In addition to normal maintenance, it is important to remove all evidence of vandalism or graffiti quickly. Quick removal minimizes the number of people who will be aware of the lapse of security and demonstrates the responsibility and responsiveness of the system.

Whenever large numbers of passengers are near each other, their perception of security is maximized. It is therefore useful to integrate routes and modes of travel and decrease headways so that vehicles are frequently arriving and leaving any particular stop or station.

Procedures used by security forces can have an impact on rider perception of security. For example, if an individual has perpetrated a crime and is on a bus or train, the offender should not be approached until he or she is leaving the vehicle. Arresting an individual on a vehicle causes significant concerns to passengers. Similarly, a number of police at a facility or stop searching for an offender can suggest that the crime was violent and would cause negative perceptions.

Encourage anonymous passenger reporting of security incidents. Bystander apathy is typically related to the concern that the perpetrator will retaliate toward witnesses. The installation of equipment and procedures that allow passengers to report crimes in progress or to later report that they witnessed a crime will encourage them to contribute information that can lead to the incarceration of the offender.

The system also needs to encourage local residents associated with town-watch activities, tenant associations, and neighborhood meetings. Systems can be effective in showing cooperation or concern for their local neighborhoods by providing speakers and programs. It is also useful to establish relationships with youth groups and provide part-time or summer jobs to unemployed youths. It is not uncommon for many activities of graffiti and vandalism to be associated with youths. Bike patrols are also an effective means for quick reaction in response modes while still providing mobile visibility of the security force.

Often local celebrities and athletes have concerns for the community and can be approached and requested to be included in public service announcements, fairs, and other activities in which they can be viewed as role models. Using retired and specially equipped vehicles as mobile public relations sites can facilitate the distribution of security and other materials and make the local community aware of security devices such as lights, silent alarms, variable message sign boards, and two-way radio communication systems typically installed on vehicles.

Establish relationships with the local news media so that they know who to call when information is needed and a rapport can be established. The news media can sensationalize security incidents. They need to understand that balanced reporting is necessary to maintain the appropriate perception of security by passengers. Establishment of such a relationship facilitates the forward movement of publicity information that the system wants to convey.

Passenger relations training of operators is also important. Since operators must often take steps to control passengers, their calm, confident, helpful attitudes can contribute to a positive impression. When passengers are being rowdy and noisy, disobeying common rules, or committing vandalism during the ride, the operator has an obligation to control the passengers. Training can give operators the skills, confidence, and professionalism to handle troublesome passengers. Adequate control of passengers makes all passengers feel more secure.

RESPONDING TO SECURITY INCIDENTS

This section addresses ways in which a system can respond to criminal activities. Beginning with immediate response to an incident, it addresses security activities from the start of the incident through its review and follow-up to reporting. It also includes the special considerations of communications, interaction with law enforcement agencies, record-keeping and reporting, and on-going system refinement. This section addresses the reactive staff activities involved in system security.

Often a system employee will observe a crime taking place. The reactions of the initial observer can have a major impact on the outcome of the incident. There are three basic options to a person who comes upon a crime: do nothing, go for help, or try to intervene. The actions that they take should depend on how they are trained and what they observe. The objective is to stop the crime from proceeding without having it escalate.

Observers must base their reactions on what level of criminal activity is taking place. Types of crime can be divided into four categories:

- Nonviolent, nondestructive regulation violations such as eating or smoking in unauthorized areas or loitering;
- Nonviolent, destructive behavior such as fare avoidance, defacing system property, and pickpocketing;
- Violent, theft-related crimes such as robbery employing a weapon; and
- Violent, assault-related crimes such as fights.

Nonsecurity employees may be able to intervene in a nonviolent criminal activity and successfully stop it. On the other hand, they would be ill-advised to intervene in a violent crime situation because of the possibility of making matters worse. The ability of employees to be able to observe a crime, determine its level, and decide on what action should be taken is totally dependent on the training that they have been provided. Training that establishes procedures for reacting to each type of incident is needed. In addition, procedures should be practiced so that employee reactions are conditioned before an incident takes place.

Once information is received that a security incident has occurred, the operator or dispatcher is responsible for putting the response system in motion. There will be a wide range of possible actions depending on the type, magnitude, and location of the incident. Actions include

- Dispatching security personnel,
- Calling the police,
- Notifying supervisors and management,
- Notifying system dispatchers and route controllers,
- Establishing on-scene communication,

• Activating the general announcement system to relay messages,
• Calling for rescue or emergency support,
• Recalling off-duty personnel, and
• Informing the media.

Technology can be an effective force multiplier in attempts to cope with security problems. However, technology cannot substitute for motivated employees who take the security aspects of their job seriously and perform their duties professionally. Technology has the potential to act as a placebo, convincing some that the system is secure because there are cameras, alarms, communications, and sensors. Each of these items allows security personnel to monitor greater areas of the system than they could personally. But no matter how good the technology, the staff that monitors it must be alert, motivated, and trained to be effective.

Communications serve as the backbone for response to a serious crime. Primarily, they are as the command and control link to coordinate the response while the crime is in progress, but they can also help keep the situation from escalating, reduce public exposure to dangerous situations, and provide an accurate record of the activity surrounding the crime for later review and analysis.

The purpose of incident follow-up is threefold. First, it is to limit and repair any harm done to individuals and property. Follow-up response will initially focus on any people who were in the vicinity of the crime to alleviate their danger and to help in their recovery. It then focuses on limiting the danger to the system from any aftereffects of the crime. The second purpose of follow-up is to collect information and evidence from the incident for possible legal action and to evaluate the effectiveness of the security system. The third purpose is to return the system to normal operation. This will involve cleaning up the site, dispersing the crowd, reopening any areas that may have been closed, and handling the dissemination of information concerning the incident.

"Security would be so simple if it weren't for all of the paperwork": this is the attitude shared by many professionals. It is not surprising if the individual sees no benefit derived from the filling out of long, apparently useless forms. The reporting part of the security process needs to demonstrate its value in terms that directly affect the persons providing the information. Information requirements can differ depending on many of the same factors discussed earlier, including the size of the system, the environment in which it operates, the amount of crime that prevails, and the authority of the system itself. Reporting information includes tapes of telephone and radio communications involving the incident; legal materials, such as the records of incident investigations, arrest records, and custody records; quantitative data or numerical information, such as cost and time necessary to draw statistical conclusions; and qualitative information, which is often narrative and requires interpretation by the user to draw conclusions. All collected data must be securely stored, and the method most typically used is computers. Computers also provide the ability to serve as the basis for generating reports. A number of safety reporting software programs and data bases are in use in the United States that include some means of security data as well. Among them are two that have been developed and refined by FTA: AERS (Automated Emergency Response System) and SIRAS (Safety Information Reporting and Analysis System).

No matter how effectively a security system has been developed and applied, some flaws and problems can be identified only after specific incidents have occurred. The security system should be kept in top form. Steps to reach this level of readiness include reviewing the policies and procedures as a follow-up to an incident review team report. It may be that the policies and procedures used were inappropriate for the particular security incident. If so, new procedures will need to be developed. Such procedures should not be developed in a vacuum; they should be thought out very carefully while anticipating any ramifications to other security procedures. It is highly desirable to use training exercises to identify ways to defeat newly created procedures. Ultimately, once the bugs are worked out and the new procedures adopted, all employees should be retrained on the new procedures and they should be integrated into the program.

SPECIAL SECURITY PROBLEMS

General

The base document from which this summary was prepared includes many security problems that are fully discussed according to a classification scheme. The length of the paper does not allow for the discussion of the procedures, but the classification scheme is summarized. Each system may want to acquire a copy of the guide, study each of the various security problems, evaluate the solutions and techniques, and decide what they may want to do.

The basic format of this classification scheme is shown as in Figure 1. The name of the security problem or issue is shown in the upper left hand corner of the figure.

"Severity" is described as low, moderate, or high, depending on how much damage, how great an injury, and how much loss may occur based on a single incident.

"Frequency" indicates the relative likelihood of the incident occurring or how often the crime may occur, relative to other problems.

"Type" of security issue refers to whether the issue is considered a general security issue, a crime against passengers, a crime against the system, or a crime against the public.

"Locations" describes where the problem occurs the most, whether on the bus, rail, on-board any vehicle, in parking lots, at stops or shelters, in the adjacent community, at facility approaches and exits, in the vehicle front or rear, at entrance/exit areas, at fare collection areas, on the platform, in corridors, in offices and garages, in any location, or various other sites.

"Areas of effect" indicates what parts of the system may be affected most directly by the incident, including passengers, vehicles, equipment, facilities, staff, or all of these.

"When" describes what time of the day or what part of the passenger's trip the incident can occur. This descriptor varies significantly depending on the problem and might include whether the incident is likely to occur while patrons are waiting, boarding, on-board, exiting the system; during peak hour, off peak, business hours, rush hours, early a.m./evening, late night; while closed; at some special time; or at any time.

"Contributing factors" include those general conditions that cause a problem or make a security breach more likely. Examples include lighting, community, staff, presence of others, fare, approach of vehicle, observation, time of day, equipment strength, police presence, secrecy, response capabilities, history of an issue, human factors, equipment power, or various other factors.

"Solution areas" summarizes the *types* of approaches and areas affected by solutions. These areas vary but may include training,

SECURITY PROBLEM		Severity:	Frequency:	
Type:	Areas of Effects:			When:
Locations:				
Contributing Factors:				
Solution areas:				
SOLUTIONS/ APPROACHES:	Cost		Effectiveness	Duration
	Personnel	Facility/Equipment		

FIGURE 1 Summary table format.

equipment, facilities design, response, public relations, community relations, communications, observation, fares, advertising, coordination, cooperation, enforcement, special materials, and contingency planning, among others.

"Solutions/approaches" provides brief descriptions of possible solutions or approaches to handling the problems. Approaches are discussed in further detail within the text, but in this figure information regarding the costs, effectiveness, and period of application is summarized for comparison. Strictly speaking, all of the costs, effectiveness, and application periods are variable, but the relative merits and drawbacks are presented for quick consideration.

"Cost-personnel" describes the relative expense in staff time and salaries generally required to effectively implement and maintain the approach to security. These costs are presented as low, moderate, or high.

"Cost-facility/equipment" describes the relative costs of obtaining or maintaining capital including new equipment, devices, or facility improvements. They vary depending on how elaborate the specific materials. In general, however, they may be described as low, moderate, or high.

"Effectiveness" notes how effective this solution or approach should be, how effective other systems have found this to be, and how likely the approach is to work alone. The real effectiveness of a program will be determined by how well it is implemented and the specific problem that it is designed to address; however, the relative effectiveness of the approach compared to other approaches is described as slight, low, moderate, high, or very effective, or variable if there are an unusually high number of other factors that dictate the success of an approach.

"Application" describes how often the solution approach will have to be applied. Equipment-based solutions need to be installed only once, for example, but training approaches are required periodically. Efforts may be required once, for each case, periodically, or on an ongoing basis.

The classification methodology can be used to summarize all security problems. For purposes of discussion, security problems have been organized into several categories:

- General security issues,
- Crimes against passengers,
- Crimes against the transit system, and
- Crimes against the public (critical incidents).

General security issues include minor problems that must be handled on a daily basis by front-line transit personnel. These issues seldom require the intervention of police and are rarely reported. They also include security-related issues that may not result in harm to people or property during a single incident but have been ignored for some time. General security issues common to all transit systems include disorderly conduct, drunkenness, crowd control, drug law violations, minor sex offenses, solicitation, homelessness, and miscellaneous misdemeanors or nuisances, such as transit rule or local ordinance violations.

Crimes against passengers are serious but somewhat less frequent. They include theft, physical assault, and sexual assault. The nature of these crimes varies, and the approaches to addressing each particular problem can take many directions.

Crimes against the transit system are particularly common. They include fare evasion; fare theft; suicide attempts; vandalism; trespassing; theft, burglary, robbery; and security of personnel.

Crimes against the public are system crimes that are not limited to the security of the passengers or the transit system. Inherently, they are extremely critical incidents, such as hostage taking, hijacking, and bomb threats.

An example of the classification scheme as applied to the crimes against passengers problem of physical assault is offered.

Physical Assault

The potential for physical or sexual assault when using transit is a significant concern. Although the incidence of assault in transit is often comparable to or less than the incidence in the surrounding community, many people perceive that they are less secure while waiting for or riding on a transit vehicle. Personnel must create a secure environment and educate the riding public regarding positive steps to take to increase their security.

Types of Assaults

Assaults in transit systems can be categorized into two types. First, there are altercations that involve a single assailant and a single victim. The two individuals may know each other or they may be strangers. This type of assault is usually not planned and usually does not involve a weapon. It may result from the release of aggression from the assailant, who is experiencing some frustrating circumstances (which in no way justifies the assault). This type of assault can occur in a number of locations, including a bus or train, a platform or stop, a station, a parking lot, or anywhere else in a transit system.

The general type of assault usually involves one or more victims confronted by a group of assailants. This type of assault is usually planned. It may not be designed for the actual victim but planned with the intent of assaulting someone. Often, the motive of this type of assault is robbery, but there are other common motives, including hate crimes (violence against certain ethnic, religious, or racial groups), crimes targeted at homeless individuals, and gang assaults of a random and seemingly inexplicable nature. These crimes take place in society at large, and transit systems are not immune.

Frequency of Physical Assaults

Assaults do not occur as often as less serious transit crimes, such as vandalism or fare evasion. The surrounding service area of the system usually determines the frequency of assaults: more often in high-crime urban areas, less often (or rarely) in small towns and rural areas. Assault victims are likely to report the incident to authorities, so the reported number of assaults in transit systems closely reflects the actual incidence.

Prevention of Physical Assaults

Systems must take measures that prevent assaults and reassure passengers that they can travel without fear of assault. The perception of security is just as important as the actual level of security. The system's actions should be very visible to both the potential criminal and the passengers. These actions include creating an environment that discourages assaults, employing visible transit security personnel, designing facilities to discourage assaults, installing closed-circuit television (CCTV), and installing alarms and call boxes.

Environment That Discourages Assaults

The highest priority should be placed on the safety and security of its passengers. As with all security problems, the most effective way to reduce the occurrence and severity of passenger assaults is to create an environment that discourages attempts. Preplanned assaults on passengers will more likely take place at times and locations where criminals believe their attack will go undetected and where escape from the scene of the incident is easy. Therefore, effective measures that a system should take involve the design and maintenance of the facility (stop or station), training of the operators and other personnel in the field, and specific security personnel and procedures.

Visible Transit Security Personnel

Visible uniformed security personnel are very effective in preventing assaults. The presence of other transit personnel, while less effective, may be more practical and require less additional expenditures. The fact that an assault will be immediately detected is the greatest deterrent to potential assailants.

Smaller transit systems may not have their own security personnel to patrol routes and stops. Instead, they rely on local police. In this case, the lead transit security officer should focus efforts in coordinating the system's resources and information with the local police department.

Facility Design To Discourage Assaults

Several facility design features are helpful in deterring assaults. Good lighting increases the likelihood that a passenger can see a potential assailant. Passengers will also feel more comfortable in a well-lit area. Areas that should be kept well-lit include station platforms, bus stops, and bus shelters.

Many rail systems have designated off-hours waiting areas in their stations. These are clearly marked portions of the station that are within sight of transit personnel. They are also part of the train platform or are close enough to the platform for easy access to arriving trains. Passengers are not required to wait at these off-hours areas, but they tend to do so, especially when encouraged through transit system promotions.

Closed-Circuit Television

An effective but higher-cost measure is the installation and use of a CCTV monitoring system. The presence of cameras at stations and platforms gives an impression to passengers and potential assailants that criminal activity will be detected. The use of CCTV enables staff to observe activities at a wide variety of locations and alert security personnel to report to a specific location when necessary.

Alarms and Call Boxes

Alarms and call boxes provide a means for passengers and transit personnel to call for assistance in the event of assault, threat, or some other emergency. Their locations must be planned for convenience of users. A transit system must also develop procedures for responding to the alarms or messages, including the inevitable false alarms. The effectiveness of alarms, call boxes, and CCTV is enhanced when used together.

Figure 2 shows the potential measures that transit systems can take to reduce assaults.

CLOSURE

In the adoption of procedures for preventing and responding to security incidents it is important to keep in mind several items.

- Fully identify, discuss, and determine how security can be proactive.
- Do not wait for security incidents to occur; anticipate them by reviewing literature and existing records and having discussions with other transit systems.
- For each and every security problem identified, formulate what solutions need to be put in place.

PHYSICAL ASSAULT	Severity: HIGH	Frequency: INFREQUENT
Type: AGAINST PASSENGERS	Areas of Effects: PASSENGERS	When: ANYTIME
Locations: Bus, Rail, Parking lot, Stop/shelter, Adjacent community, Platform, Corridors		
Contributing Factors: Poor lighting, No police presence, No other staff presence, Awkward facility design		
Solution areas: Enforcement, Equipment, Facilities design, Cooperation, Observation, Training		

SOLUTIONS/ APPROACHES:	Cost		Effectiveness	Application
	Personnel	Facility/Equipment		
Coordination with local police force	LOW	LOW	VARIABLE	ONGOING
Visible transit security personnel	HIGH	LOW	HIGH	ONGOING
Presence of other transit personnel	LOW	LOW	MEDIUM	ONGOING
Good Lighting	LOW	MEDIUM	MEDIUM	ONGOING
Off hours waiting areas	LOW	LOW	HIGH	ONGOING
Closed circuit television	MEDIUM	HIGH	HIGH	ONGOING
Alarms/call boxes	MEDIUM	MEDIUM	MEDIUM	ONGOING

FIGURE 2 Assessing physical assault.

- Those solutions should be in terms of the establishment of detailed procedures that are well documented and tested before adoption.
- Develop and implement an initial training and retraining program for all transit personnel regarding the procedures associated with each of the security problems.
- Once everyone is initially trained, institute the procedures.
- This entire process should be dynamic. Nothing stays the same, and new information is gathered on a regular basis. It is important for the system to review and update its procedures regularly.

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Perception and Incidence of Crime on Public Transit in Small Systems in the Southeast

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The initial report of a set of studies undertaken in small cities in the Southeast included questions to police departments and transit agencies in the region and a set of personal interviews with drivers, passengers, and nearby residents of the public transit system in Greensboro, North Carolina. The results indicate little violent crime on transit with varying perceptions of safety depending on the gender and race of the subjects, yet residents perceive the system as being unsafe. It is recommended that transit security focus on means of countering such perceptions.

The problem of crime is a key element in the decision by urban residents to use public transit. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) contains a number of provisions relating to transit security and crime. The focus of these sections is on identifying and removing situations that contribute to an unsafe or insecure transit system. The importance of security is emphasized by Section 3013 of ISTEA, which requires transit operators to "expend not less than 1 percent of funds received . . . for transit security projects." These projects are defined as "increasing lighting within or adjacent to transit systems . . . increasing camera surveillance . . . providing emergency telephone lines . . . or other projects intended to increase the security and safety of existing or planned transit systems." This paper investigates the incidence of criminal offenses on a transit system in a small Southeastern city and the perception of crime of transit users and potential users.

PRIOR STUDIES

Concern about the relationship between crime and personal safety and the use of public transit is not a new issue. Several papers on the topic focus on fear of crime as a deterrent to use, driver safety, station design to reduce crime, legislative actions, and police and staffing issues. Most published literature deals with systems in large cities, usually subways, but there is no information on small bus systems.

Public Opinion Studies

A number of studies examine the perceptions and opinions of urban residents toward crime and personal safety on transit. Paine et al. found that personal security was the top item of 33 variables that influenced the use of transit in Philadelphia (*1*). Hartgen, in analyzing these data, concluded that personal safety and security was a key overlooked predictor of travel behavior (*2*). Thrasher and Schnell show that the security problem was widespread and the risk of being a crime victim was estimated to be twice as large as in a nontransit situation (*3*). Shellow et al. report an evaluation of a demonstration of electronic security systems for rapid transit (*4*). Sinha and Roemer examine perceptions of crime on the Milwaukee bus system and relate them to other factors influencing travel behavior such as travel time and fare (*5*). Koppelman and Pas identify "psychological comfort" as a significant predictor of mode choice (*6*), and Benjamin and Sen found that 9 of 23 studies identified security to be an important factor (*7*).

More recently, Levine and Wachs conducted a survey of households to measure the incidence of bus crime in Los Angeles (*8*). They report that "the incidence is 20 to 30 times greater than Southern California Rapid Transit District reports indicate." In the study they focus on three high-crime stops. Certain population segments appear to be particularly vulnerable to transit crime, including the elderly (*9*) and women (*10*).

Most recently, in an unpublished report, the Metropolitan Atlanta Rapid Transit Authority (MARTA) surveyed Atlanta transit riders and asked their opinions and perceptions about safety on the transit system. It found that 61 percent of the respondents agreed with the statement "I would ride MARTA more if I felt safer."

Studies of Proposed Countermeasures

Many studies review countermeasures for crime. Most of the published studies examine countermeasures at subway stations (*4,11*). Hoel discusses countermeasures on bus transit and classifies them into measures that can be taken inside vehicles (i.e., alarms and radios) and measures that can be taken at bus stops (i.e., lighting) (*12*). Wachs and Pearlstein point out that countermeasures for rapid transit and inside buses are well understood, but that "the physical environment of public transportation is so extensive and varied that it cannot be made secure without meticulous attention to the larger human environment of which it is a part" (*13*). In their report, they recommend individual design of bus stops and nearby areas to create a setting that discourages crime. Levine et al. discuss environmental effects of bus stops on the incidence of crime and recommend specific countermeasures (*14*), and Balog et al. suggest a comprehensive approach (*15*).

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STUDY DESIGN

To understand personal security, it is first necessary to identify criminal offenses. Most law enforcement agencies use the Uniform Crime Reporting System to define and classify offenses. The FBI divides offenses into two groups: Group A crimes are more severe and include assault, burglary, drugs and narcotics, murder, and larceny; Group B includes disorderly conduct, drunkenness, and trespassing (*1*).

This study was designed to estimate the incidence of criminal offenses on or related to bus transit systems in small urban areas of the Southeast. Since there was no one reliable source of information on the "true" level of criminal activity, it was decided to use a combination of sources to first find an estimate of the incidence and then compare results from the various sources. Finally, responses were obtained to assess countermeasures for serious crime problems that are identified earlier. Thus, information was gathered from five sources: local police, transit agency, drivers, passengers, and urban residents who lived near bus routes. Information from the first four sources provided an estimate of crime from different perspectives. Information from the last source was a perception of crime from people who had no direct experience with the transit system. Each study was completed with a different sample of people.

Agency Studies

City police and transit managers were contacted to gain a perspective on what information on criminal offenses near or on transit was recorded by these agencies in their communities. The survey was conducted in two stages in 21 communities in the Southeast region (FHWA Region 4). In the first stage, the 21 community agencies were contacted to find what information (if any) was available on transit crime. In the second stage, police departments and transit agencies were contacted with specific questions on criminal offenses near or on transit.

Only the Greensboro Police Department was contacted because the other departments indicated that they did not classify the location of crimes as being near or on transit. The only other city to report crimes on or near transit was Orlando, Florida. The transit agency questionnaire consisted of detailed questions on countermeasures, on criminal offenses reported on or near the transit system, and on opinions concerning agency policies. Questionnaires were submitted to the 21 transit agencies that were contacted, and eight were returned.

Personal Studies

Greensboro, North Carolina, was chosen because it is a typical size for a city located in the Southeast (approximately 200,000 population), it has a public transit system, and the personnel at the transit authority indicated a willingness to cooperate fully with the study. The personal studies included the studies of residents, passengers, and bus drivers.

The first step in preparing the personal studies was to conduct focus groups. Three focus groups were held, one in Charlotte and two in Greensboro. At each session residents were asked to express their feelings about and reasons for choices about traveling on transit. Focus group procedures are often open-ended, but since the authors were unwilling to predetermine whether safety would even be an issue, the authors adopted a more guided group discussion known as nominal group process. The results of these focus group sessions were used as the basis for the development of the other individual questionnaires.

Questions for the residents, passengers, and drivers were worded to enable comparisons within sociodemographic groups and between the study groups. All of the surveys were completed during spring 1993.

Resident Study

The study of residents of Greensboro was a telephones survey. The telephone numbers were found by random digit dialing using telephone number prefixes for areas that were along the routes of the bus system. Five hundred people answered the questionnaire.

The survey instrument consisted of questions on criminal behaviors observed by each resident, precautions taken during travel, and opinions on personal security while traveling. Major parts of the questionnaire referred to a specific list of crimes and asked if they were "a problem in your neighborhood," "a problem around bus areas," "a problem on the Greensboro buses," or criminal behaviors that "you have personally experienced." Then a list of locations in the city was presented and respondents were asked if they would feel very safe, somewhat safe, somewhat unsafe, or very unsafe. Next, respondents were presented a list of security problems while traveling and asked if they avoided them. The final set of attitudes was found by asking how often they would use the bus if each one of a list of service improvements was made. The improvements included operating characteristics such as lower bus fares and safety features such as better street lighting at bus stops.

Passenger Study

The questions were similar to the questions that were asked of the residents. They consisted of questions about the mode of travel, frequent trip purposes, criminal offenses that were observed while traveling by different modes, attitudes toward safety while traveling, travel precautions, and recommended countermeasures. Questionnaires were administered in a personal interview format of passengers at bus stops throughout the city. There were 392 passengers who answered the questionnaires; 319 of these proved to be complete enough to use.

Bus Driver Study

The bus driver study consisted of a questionnaire that was completed by each of 33 drivers during interviews on break. There are 40 full-time drivers and 15 part-time drivers on the system. Drivers were contacted on three separate days, and all drivers who were contacted completed the questionnaires.

The questionnaire was similar to the others and consisted of questions on criminal offenses that were witnessed by the drivers and opinions on precautions taken by people as they travel and on recommended countermeasures.

INITIAL STUDY RESULTS

Agency Studies

At the request of the authors, the Greensboro Police Department completed a report of offenses committed on or near public transit. There was one Group A offense reported (aggravated assault) at a bus stop and one Group B offense (misdemeanor breaking and entering). Police department personnel indicated that there was a lack of confidence in the small number of incidents reported because officers usually identify locations by intersections.

The transit agency questionnaires indicated a varying level of criminal offenses at different urban areas. The largest reported offense was assault, which was reported 21 times in one of the properties. In another property, theft was reported 18 times during the past year. For most offenses and properties there were no reported incidents of Group A crimes, and in the few instances in which crime was reported, the crimes were less than three incidents for the year. In Greensboro, no crimes were reported to the transit authority or the management firm (ATE Management). The variation in criminal offenses between the different urban areas may be a reflection of different urban environments or different crime reporting systems.

Personal Studies

Table 1 presents a summary of the backgrounds of the three of the subjects in the three surveys. These backgrounds differed, making it possible to contrast the perceptions and opinions of the three groups. The residents were 63 percent female and 22 percent African American, the bus passengers were 57 percent female and 86 percent African American, and the bus drivers were 19 percent female and 81 percent African American. Most households sizes ranged from 1 to 4. Eight percent of the respondents indicated that they never used transit, and only 2.6 percent indicated that they used transit more than once a week.

Of the residents who rode the bus, the most frequent answer as to why was "no other means of transportation" (45 percent). Most people said that they did not ride the bus because they owned an automobile. As expected, most of the bus passengers rode the bus to work (31.7 percent).

TABLE 1 Comparison of Respondent Background for Three Surveys

Background	Resident	Passenger	Driver
Sample Size	500	319	31
Percent African American	22	86	81
Percent Female	57	63	19
Mean Age	40	37	42

Perception of Crime Near Transit

The respondents for each survey were asked about their perceptions of crime on or near transit. Results are given in Table 2. For the residents who responded when asked about offenses in bus areas, the offenses receiving a "yes" response most frequently were obscene language (27 percent), disorderly conduct (23.2 percent), panhandling and begging (23.5 percent), and drunkenness and vandalism (18.4 percent). Violent crimes were indicated in 8.1 percent of the responses. Of these respondents, 74 indicated they had experienced some offense firsthand.

The majority of bus passengers did not report any offenses as problems on the bus. The offenses that were reported most frequently were disorderly conduct (22.7 percent) and drunkenness (16.6 percent).

For the drivers, the most frequently reported offenses were obscene language and drunkenness, which were seen by 81.3 percent of the drivers. The most serious crimes were drug use or sales, which were witnessed by 25.8 percent of the drivers on their buses. No drivers reported violent crimes such as assault, murder, or robbery.

In summary, only a small percentage of residents perceived crime on transit as a problem, and the bus passengers and drivers indicated that there is little or no serious crime on transit. Despite this, the passengers and drivers say that there is a problem with Group B offenses such as obscene language and disorderly conduct.

TABLE 2 Percentage Finding Offenses a Problem near Bus System

	Responses (%)		
Offense	Residents	Passengers	Drivers
Obscene language or disorderly conduct	5.3	22.7	81.3
Panhandling/begging	2.4	9.4	50.0
Drunkenness	4.2	16.6	81.3
Vandalism	0.0	6.5	9.4
Verbal or physical threats	1.8	5.5	48.4
Drug use/sales	4.0	4.9	25.8
Robbery	1.7	3.9	0.0
Violent crime such as assault or murder	0.0	3.4	0.0

Perception of Safety

The respondents for each survey were asked about their perceptions of safety on or near transit. Results are presented in Table 3. The situations that people perceived as unsafe most frequently were waiting for the bus downtown (46.8 percent), waiting at a bus stop downtown (47.7 percent), walking downtown (40.1 percent), walking in a park (37.3 percent), and transferring at the proposed bus terminal at the Depot (44.7 percent). (The Depot is the old Southern Railroad train station that has been restored as a meeting center and is located in the southeast corner of the central business district. It currently serves no function as a transportation facility but it has been proposed as a transfer terminal for all transit routes as well as a station for intercity rail and bus passengers.) There was also the feeling that suburban environments were unsafe, including shopping in a suburban mall (30.0 percent), waiting at a bus stop in the Greensboro suburbs (32.4 percent), and walking to catch the bus in the suburbs (32.2 percent). In fact, the only environment that was widely seen as safe was home (97.2 percent).

For the bus passengers, 90 percent of the respondents felt very safe waiting at a bus stop in downtown, walking in downtown Greensboro, and transferring at the proposed bus terminal at the Depot. Surprisingly, when these same respondents were asked how they felt about the suburbs, 15.1 percent thought that these areas were somewhat unsafe and 4.1 percent perceived them as very unsafe. Of these respondents, 29 indicated at least one route that was unsafe.

For the bus drivers, overall, 90 percent agreed that passengers believe that traveling by transit was very safe or somewhat safe. However, a small percentage indicated that travel in the suburbs was unsafe for their riders.

Personal Experience with Crime

The respondents for each survey were asked about their personal experience with crime on or near transit. Results are presented in Table 4. Of the residents, 74 indicated that they had experienced some offense firsthand, and 29 of these (5.8 percent) indicated that they had experienced robbery. Only 40 of the passengers indicated experiencing any of the offenses firsthand.

Precautions While Traveling

Each group was asked about the precautions that they take while traveling. The precautions that people used most often were avoiding strange-looking people (80.2 percent), travel after dark (56.7 percent), and groups of teenagers (54.2 percent). The precaution of avoiding people of a different race was given by 15.6 percent of the respondents. For the bus passengers, three precautions were most frequently cited: avoiding travel after dark (41 percent), strange-looking people (40.8 percent), and drunken people (33.8 percent). The precautions that most of the drivers observed their passengers taking were avoiding travel after dark and avoiding

TABLE 3 Percentage Rating Environments Unsafe

	Responses (%)		
Environment	Residents	Passengers	Drivers
Waiting at a Bus Stop in Downtown	37.7	8.0	9.3
Walking in Downtown	40.1	8.4	9.3
Transferring at the Depot	34.7	9.5	6.3
Walking in the Suburbs	32.4	19.2	18.8

TABLE 4 Offenses Experienced near Transit System and in City

	Responses (%)			
	Residents		Passengers	
Offense	Transit	Citywide	Transit	Citywide
Obscene language or disorderly conduct	0.40	2.83	1.07	5.90
Panhandling/begging	0.20	2.63	0.80	2.41
Drunkenness	0.40	1.41	0.54	4.56
Vandalism	0.00	4.44	0.00	1.07
Verbal or physical threats	0.20	2.22	0.00	1.61
Drug use/sales	0.40	1.01	0.27	1.61
Robbery	0.20	6.06	0.00	1.34
Violent crime such as assault or murder	0.00	0.40	0.00	0.27

TABLE 5 Percentage of Responses by Survey (Bus Passenger versus Residents)

	Responses (%)		
Question (race or gender of respondents)	Resident	Passenger	z statistic
Very Safe Waiting Downtown (White)	6	57	8.67
Very Safe Waiting Downtown (Black)	7	47	6.42
Precaution Travelling Alone (Females)	63	27	6.82
Precaution Travelling After Dark (Females)	70	39	5.91

travel alone. The drivers also observed that passengers avoided drunken and strange-looking people.

Suggested Improvements

Improvements that would encourage more regular use of buses were mostly operational changes, but at least some additional bus use was indicated by 20.8 percent of the subjects with improved lighting at bus stops. The improvement that was most frequently recommended by the drivers was lighting at the downtown terminal, at neighborhood stops, and on neighborhood streets. Most drivers also agreed with the idea of security personnel at the downtown terminal. The idea that was most frequently suggested in an open-ended question was the addition of a public telephone at each of the downtown terminals.

Comparison of Responses by Gender and Race

The responses for each question were cross-tabulated with gender and race for each question in all three studies. In general, chi-square statistics were not significant at the 5 percent level for these cross-tabulations of responses for gender and race. However, cross-tabulation by survey indicated significant differences in the proportion of answers. This is indicated in Table 5. Statistics are reported for the proportion that answered positively to the response variable by race or gender in each survey group. In each case, there is a significant difference in the proportion of respondents answering these questions who are either bus passengers or residents.

In contrast, when the survey groups are divided by race or gender, in each case the proportions of respondents answering each question were not significantly different. These results are confirmed by a more detailed analysis by of the interaction of gender and race. In almost all cross-tabulations, the relationship between the interaction term and the response variable was not significant. A significant relationship was found in only a few cases such as the sense of safety by residents while walking to catch the bus downtown (chi-square = 27.8, df = 9) and the precaution by residents of not traveling alone (chi-square = 68, df = 3).

CONCLUSIONS

There are three important aspects to the research: first, a picture of the "true" level of crime on transit; second, the perception of personal safety on transit; and third, the countermeasures that should be implemented to reduce one or both of these.

"True" Level of Crime

The perceptions of the drivers and riders that there is a general lack of violent (Group A) crimes on transit is consistent with police records and reports by the transit authority. In fact, although a small percentage saw crimes in lesser categories as a problem, only a handful of riders reported personally experiencing any offenses at all in any category.

As an example, 1.7 percent of the residents perceived robbery to be a problem, but only 0.2 percent of the residents and none of the passengers or drivers reported experience with robbery near transit, and the police department and the transit agency had no record of any robbery associated with transit.

The largest number of passengers to say that they had personally experienced a crime were the four subjects who had experienced panhandling. There were fewer responses in the other categories. This is confirmed by the resident survey, where the largest frequencies to experience any crime in any category during the past 2 years related to traveling on transit were the two subjects who reported experiencing panhandling and obscene language and the person who reported personally experiencing a robbery.

Using all of the surveys together, there is close to no violent crime on transit in Greensboro. The lack of violent crime on transit compares favorably to the 0.40 percent reported in the resident survey for Greensboro overall.

Perception of Crime

Despite the low level of crime of any kind reported on the transit system, almost half of the residents of the community express a fear about traveling by transit or walking in the downtown area. Those who have direct experience do not express that same fear. Perhaps even more worrisome is the overall unsafe feelings that are expressed for all settings by the residents. Within this milieu, it would be difficult to eliminate all fear just by improving transit safety.

The pictures of travel in Greensboro are drawn by the three different populations. The drivers and riders paint a safe picture of riding transit and traveling downtown with no experience with violent crime. These same subjects demonstrate the largest fear of traveling in the suburbs. The nonusers of transit appear most fearful, particularly of traveling downtown. On closer examination, these feelings are generally explained not by gender or race but by experience traveling on transit. Those who have experienced traveling downtown on transit perceive travel to be safe.

Countermeasures for Criminal Offenses Near Transit

The countermeasures must be threefold:

1. To create environments on or near transit that provide the perception of safety,
2. To conduct a campaign to educate people about the safety of public transit, and
3. To develop economic incentives and system performance levels that will entice people to experience the level of safety firsthand.

The physical countermeasures are a set of measures related to recommendations by Pearlstein and Wachs (*13*). However, since there is no crime to speak of, the measures must be aimed at creating the perception of safety. More and better lighting, police and security surveillance, and the addition of telephones at the terminals all seem appropriate.

An educational campaign should emphasize how safe the transit system already is: both the actual statistics and the feeling of safety of current riders. An additional point is that transit is much safer overall than automobiles, which are responsible for serious injuries and fatalities from accidents every day.

An additional analysis will be required to recommend specific actions that would attract people to at least try transit firsthand.

Further detailed analysis of these surveys will clarify these findings. In many ways Greensboro is a typical small city in the region, and these findings are likely to apply elsewhere.

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Public Fear of Crime and Its Role in Bus Transit Use

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Information about how personal safety concerns influence bus transit use in smaller cities is not readily available. Bus riders and residents in Greensboro, North Carolina, were surveyed in April 1993 to determine attitudes, ridership levels, and motivations for choice. It was found that most riders are frequent users, but residents rarely ride. Resident concerns about personal safety were two to three times greater than riders' concerns, but both groups were less concerned about personal safety on or near the bus system than about general safety in the community. Residents were most fearful of activities in downtown Greensboro. Both residents and riders saw the major bus-related problems as disorderly conduct, drunkenness, and panhandling. Residents and riders feel safest at home and in their neighborhoods. Only a few residents or riders have personally experienced a crime problem in the last 2 years. Generally, blacks, whites, men, and women all experienced similar concerns: the big difference was between riders and residents (generally nonusers of the service). More than 50 percent of residents take precautions to protect personal safety, primarily avoiding drunken people, strange-looking people, groups of teenagers, and travel alone or after dark. Women take more precautions than men. But reduced concerns about safety would not increase bus ridership as much as basic service improvements. It is concluded that image links between bus service and perceived high-crime areas such as downtowns are major deterrents to increased ridership, even though bus service itself is perceived as quite safe.

Images of crime cast wide shadows over American cities. Fact or fabrication, accurate or not, the public's perception of crime in the city creates an image of city centers that are less safe than their suburbs, causing their workers to flee to the "safer" suburbs after work and giving most downtowns the appearance of ghost towns during evening and night hours. Fear of crime alters the spatial, economic, and social dynamics of cities.

Public fear of crime spills over into the provision of public transit. A mounting body of evidence suggests that public concerns about personal safety may well be one of the most important reasons that many people choose not to use public transit, particularly within larger urban centers. Although there is some disagreement on just how concerns about personal safety affect ridership, fear of crime and concern for safety do appear to be key elements in the decision to ride or not. Yet transit has a relatively good personal safety record, particularly in smaller urban areas. Does the evidence which comes from research in larger cities apply equally well to smaller ones? Does fear for personal safety and the perception that crime occurs more on or near transit facilities inhibit ridership in smaller cities? These are the primary questions addressed in this study.

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STUDIES AND FINDINGS ON TRANSIT CRIME

Concern about the relationship between crime, personal safety, and use of public transportation systems is not a new issue, and although the literature is not vast, much is written on the topic. Previous research generally focuses on such issues as

- Fear of crime as a deterrent to use,
- Driver and agency personnel safety,
- Station design for crime reduction,
- Legislative actions, and
- Police and other staffing issues.

Several studies have touched, directly or indirectly, on the public's view of crime and personal security in travel choices. In the mid-1960s, Paine et al. found that personal security was the top item of 33 variables that influenced use of transit in Philadelphia (*1*). In analyzing these data, Hartgen concluded that personal safety and security was a key overlooked variable in transportation service (*2*). Thrasher and Schnell showed the security problem (both perception and reality) to be widespread among U.S. transit companies (*3*). They estimated that the risk of being a crime victim in a transit situation was more than twice the risk in a non-transit situation. In more recent work Wachs and others have investigated and quantified crime in Los Angeles (*4,5*). Wachs estimated more than 800 "serious crimes" on the Southern California Rapid Transit District bus system in 1981. The vast majority of these were in only a few high-crime areas.

More recently, Ball and Mierzejewski found that only 16.1 percent of respondents in a nationwide survey thought bus was the safest mode of travel, behind 58.9 percent for the automobile (*6*). In his chapter on security and public transportation, Hoel notes that "transit crime is extensive in most large US cities, and its magnitude may be far greater than is shown by the published statistics" (*7*). In a summary of studies of attitudes and travel behavior, Benjamin and Sen found that 9 of 23 studies identified security to be an important factor in transportation choice (*8*). Koppleman and Pas found that the more abstract concept of "psychological comfort" was a significant predictor of travel decisions (*9*). Certain segments of the population appear to be especially vulnerable to transit crime; the elderly (*10,11*) and women (*12,13*) have been identified as particularly at risk. In both cases, the data point to a high perception of risk and fear of use of the transit by these groups, particularly at night.

In several states, notably Illinois and New York, legislative commissions in the past 10 years have studied the issue of transit crime—primarily on the subway—and ways to control it. The suggestions have been wide-ranging but usually involve increasing policing and security forces and patrols (*14*). Local agencies have also studied the issue, generally concluding that more police, better lighting, and greater surveillance with camera and radio contact is the key to reduction of crime (*15,16*).

It is a rare study of transit crime that does not end with a list of suggested countermeasures intended to reduce the problem. Typically, these measures fall into several broad categories:

- More security and patrol, such as adding more transit police, increasing the frequency of visits to stations, police on trains or buses, and better coordination with transit police and city police;
- Use of technology, including surveillance cameras, radio contact, and warning or emergence systems on vehicles;
- Design actions, particularly station layout to increase visibility, better lighting, recessed walls, limited access to restrooms and elevators, platform layouts, and column locations; and
- Better information, including media campaigns, posters helpline instructions, antidrug messages, and similar items.

Thus the literature is replete with studies about transit crime, the vast majority of which focuses on environments in large cities or subways, especially station design and police task forces. Less is known about bus system crime and even less about crime on bus systems in smaller cities.

Opinion data reveals that fear of crime is a major consideration in travel plans for many transit users, particularly the elderly and women in larger cities. Again, however, comparatively little is known about how fear of crime might act as a deterrent to transit use in smaller cities.

RESEARCH QUESTIONS AND HYPOTHESES

This study was begun to determine how issues of personal safety affected the decision to use bus transit in smaller urban centers. Previous work suggests that concerns about personal safety could harm public attitudes about using transit services in larger urban centers. To explore how personal safety or crime issues would inhibit ridership in smaller cities, a project based on survey research was designed to examine the relationship between fear of crime and bus ridership in Greensboro, North Carolina, a midsized city of about 200,000 population. On the basis of two exploratory focus groups (used to probe more deeply into reasons for riding buses or not), and the literature, a series of research questions and hypotheses was formed:

Research Question 1

How does fear for personal safety affect bus ridership in Greensboro?

- Hypothesis 1a: Fear of crime inhibits bus ridership.
- Hypothesis 1b: Perceptions of crime and personal safety on or near the transit system vary significantly by gender and race.
- Rationale: In the literature personal safety issues emerged as a critical issue affecting ridership in large systems and in subways. Results of focus groups done in Greensboro supported the link between safety and ridership. Both the literature and focus groups indicated that women were more concerned about victimization and had significantly different perceptions of crime than men, and blacks had different perceptions of crime and safety than did whites.

Research Question 2

Do the perceptions of crime and personal safety of riders differ significantly from those of nonriders?

- Hypothesis 2: Perceptions of potential victimization will vary by experience with the bus system; riders will have less fear of victimization and nonriders greater concern for crime and personal safety.
- Rationale: Since riders are more familiar with bus service, they would perceive less of a link between crime and bus service than nonriders, assuming of course that bus systems are generally safe. Results of the focus groups, once again, verified this assumption.

METHOD

The research questions and hypotheses were addressed using a combination of survey techniques to collect the data. First, focus groups in two cities in North Carolina (Charlotte and Greensboro) were used to clarify the research questions and identify the key relevant terminology and phrasing for survey questions. Next, three additional surveys were done: a survey of the general population that was administered by telephone; a survey of bus riders administered as a face-to-face, on-board survey; and a face-to-face survey of bus drivers. This paper deals primarily with the phone survey of the general population (resident survey) and the on-board rider survey. The full study, undertaken by the Transportation Institute at North Carolina A&T State University, Greensboro, is reported elsewhere (*17*).

On-Board (Transit Rider) Survey

The on-board survey was conducted to explore the feelings and perceptions of Greensboro transit riders of their bus system and their own personal safety. Survey respondents were drawn from the general (bus riding) public that faced the "reality" of crime and safety on Greensboro's transit system. Questions were composed to query the survey respondents on a number of issues: frequency of use, problems (both those personally experienced and those perceived) in and around buses, precautions taken to ensure safety while moving about in Greensboro, attitudes toward personal safety in various locations, and various demographic variables.

The on-board questionnaire was administered in Greensboro using face-to-face interviews with transit riders, primarily during peak ridership hours. Surveys were conducted at bus stops throughout the city from April 27–29, 1993. Most the surveys were completed at the downtown transfer locations where a large number of riders usually gathered for their next transfer. Riders at these locations were easier to approach because they were seated and more relaxed and because they felt relatively secure in the numbers of people that surrounded them. Overall, 389 riders were surveyed, but incomplete responses about race and gender limited the usable data set to 317 cases.

Telephone (Residential) Survey

The phone survey was directed toward a broader (nonriding) segment of the general public who lived within reasonable access to bus service. Data collection and analysis, indeed the research questions, were predicated on the ability to directly compare the views of both transit riders and the general, nominally nonriding public. Thus, many questions on each survey instrument were worded exactly the same. Since more information could be collected during the phone interviews than during the busy bus trip, the phone questionnaire was longer and more comprehensive than the on-board instrument.

Surveying was done by the Urban Institute at the University of North Carolina-Charlotte. Households were randomly selected from the Greensboro phone book. Only households within phone prefixes adjacent to the transit routes were included in the sampling frame. Calls were made during the evening hours. Survey durations averaged 5 to 7 min, and the final sample size of the phone survey was 500.

FINDINGS

Summarizing Survey Results

Overall the survey sample successfully mirrored the general population from which it was drawn. Respondents to the resident (phone) survey were reasonably close in race and age characteristics and in average family size and employment status to the broader population of Guilford County in which Greensboro is located (Table 1). The phone sample underrepresented the percentage of men in the general population.

The rider (on-board) survey showed that most riders were black, women, and under 30 years old. This compared closely to recent national profiles of transit ridership but was quite dissimilar to the general population characteristics of Guilford County and the resident survey.

Ridership Patterns

Results of both surveys indicated substantial differences in transit ridership patterns of residents and riders (Table 2). In the aggregate, only 1.6 percent of residents reported using the bus to get to work or shopping and only 2.8 percent to get to school. Most residents (94.1 percent) either did not use the system or used it only rarely. Those bus trips reported by residents were overwhelmingly work and personal business and were primarily morning and late afternoon trips. In the rider survey respondents reported using the system frequently or occasionally (77.9 percent). Patterns of ridership—frequency of use—were substantially similar for blacks, whites, males, and females.

Riders mentioned a wide variety of reasons for using the bus. The single most important reason was for "transportation to work," mentioned by 28.6 percent of riders, followed by "lack of other transportation" (25.5 percent), "shopping" (12.1 per-

TABLE 1 Statistics on Residents and Riders

		Guilford Co.		Percent of Respondents Resident Survey	Rider Survey
Gender	M	164,204	47.2	36.2	42.8
	F	183,216	52.8	63.8	57.2
			100.0		
Race	African-American	91,655	26.6	22.0	85.3
	White	249,584	72.4	75.4	14.4
	Hispanic	2,887	0.8	0.8	0.3
	Other	818	0.2	1.9	---
			100.0		
Age	18-21	27,464	10.2	11.9	24.9
	22-29	47,713	17.7	18.0	25.9
	30-39	58,445	21.7	21.5	20.9
	40-49	46,751	17.3	15.4	8.8
	50-59	32,365	12.0	11.7	6.6
	60-69	29,577	10.9	11.3	6.6
	70 +	27,358	10.2	10.1	2.8
		269,673	100.0		
Employment	Full Time			50.7	
	Part Time			12.7	
	Retired			18.6	
	Student			11.7	
	Other			6.3	
Family Size	1	36,576	26.6	18.3	
	2	47,509	34.5	39.5	
	3	25,024	18.1	17.5	
	4	19,008	13.8	16.5	---
	5	6,553	4.8	7.7	
	6	1,980	1.4	0.4	
	7+	1,054	.8		
Sample Size		137,695	100.0	497	297

TABLE 2 Modes of Travel and Frequency of Bus Use (%)

	Resident Survey			Riders
Mode of Travel	**Work**	**School**	**Shop**	
1. Drive alone	68.7	14.2	72.9	
2. Ride with family	4.8	2.0	19.9	
3. Carpool (non-family)	2.6	1.2	2.6	
4. Bus	1.6	2.8	1.6	
5. Walk	1.6	4.2	0.4	
6. Other	0.8	0.6	1.2	
7. Don't go to ____	19.9	74.9	1.4	
	100.0	100.0	100.0	----
Frequency of Bus Use (N=497)				
1. Never		88.3		----
2. Rarely (few trips/yr)		5.8		16.1
3. Seldom (1-3 days/mo)		1.6		10.1
4. Occasionally (1-4 days/wk)		2.6		22.1
5. Frequently (5+ days/wk)		1.6		50.8
6. DK/NR		-----		0.3
		100		100
Purposes for bus use (N=46)				
1. Work		30.4		
2. School		6.5		
3. Shopping		10.9		
4. Social recreational		17.4		
5. Personal business		23.9		
6. Other		10.9		
		100		----
Time of Day of Bus Use (N=42)				
1. Morning 6-9 am		28.6		
2. Late Morn 9-12 am		19.1		
3. Early Afternoon 12-3 pm		9.5		
4. Late Afternoon 3-6pm		9.5		
5. Evening		2.4		
6. Commuter (am & pm)		28.6		
7. Other		2.4		
		100		

cent), and "school" (8.2 percent). One of these four reasons for riding was given by more than 75 percent of all riders. Other reasons for riding were scattered among 32 other responses.

On the other hand, respondents from the resident survey who said that they were riders listed somewhat different reasons for riding. Three responses accounted for 64.5 percent of all the reasons residents gave for riding the bus: "lack other transportation" (43.5 percent), "convenient" (12.9 percent), and "special event" (8.1 percent). Although they used the bus occasionally, the resident-survey bus users saw the system as a backup to use when other modes were unavailable.

Reasons for Not Using Bus Services

In the resident survey, nonriders were asked why they did not use bus service. A variety of reasons were given (more than 30 were mentioned) but most respondents focused on just a few reasons. Most respondents in the resident survey perceived the system as personally unnecessary, inconvenient, not available, not efficient and unsafe. Almost 38 percent said they did not ride because they "had a car," 19.9 percent said it was "not convenient," 13.1 percent said they had "no need to use" buses, 11.8 percent said buses were "not available near home," 4.6 percent said they had "no information" about buses, 2.6 percent mentioned reasons of "personal safety," and 2.1 percent said buses were "not time-efficient."

Clearly in Greensboro there was a lack of bonding between most residents and the bus system. Given the pervasiveness of these images among residents, it was surprising the system had as much ridership as it did.

Perceptions of Personal Safety Problems

Both the rider and resident questionnaires included sections that focused on perception and actual experience with a series of "problems" or criminal activities. Among the problems listed in the questionnaires were obscene language, panhandling, drunkenness, vandalism, verbal or physical threats, drug use or sale, robbery, and violent crime such as assault, rape, and murder. Perception of personal safety was measured by asking respondents if these matters were a problem around bus areas and in their own neighborhoods. Respondents were also asked about their personal experiences with these problems. Table 3 indicates how residents and bus riders responded to these questions.

Residents generally viewed the problems in Table 3 as community-wide problems more than ones that characterized their own neighborhoods. Vandalism and robbery were mentioned most frequently as problems (in neighborhoods); about 28 and 26 percent of residents thought that vandalism and robbery, respectively, were problems in their own neighborhoods. Fewer than 15 percent of residents thought that any of the remaining problems were prevalent in their neighborhoods. When asked if these problems

TABLE 3 Perceptions of Personal Safety Problems by Residents and Bus Users (%)

Problem	Residents: Is This Problem in Your Neighborhood	Residents: Problem on Buses	Residents: Problem Around Buses	Riders: Problem Around Buses
Vandalism	27.8%	10.0	18.4	6.0
Robbery	26.4	8.3	13.3	1.6
Obscene language/disorderly conduct	15.5	23.0	26.9	22.7
Drunkenness	14.0	18.2	23.5	17.4
Drug use/sales	12.5	9.0	13.4	3.8
Violent crimes	12.1	3.9	8.1	2.2
Panhandling/begging	10.1	13.9	23.2	8.8
Verbal/physical threats	7.8	8.5	7.8	4.4
	N=490	N=201	N=245	N=317
Personally experienced a problem?		15% Residents		8.2% Riders

were prevalent around buses, both residents and riders suggested that all problems were less significant on buses or around buses than in their own neighborhoods. In all but two cases, bus riders perceived problems to be much less severe (50 to 70 percent less) around buses than did residents.

There were, however, three notable exceptions to the general feeling that such problems were less significant near buses than in neighborhoods. Both residents and riders perceived obscene language and disorderly conduct, drunkenness, and panhandling and begging were problems that were (30 to 60 percent) more prevalent near or on buses than in the neighborhoods. In fact, the results suggest that these three problems may well be important factors in accounting for negative perceptions of transit and fear for personal safety near transit.

Coming to an appreciation of how such relatively lower order "crimes" or problems influence ridership depends, in part, on recognizing that perception of crime, safety, or "problems" around bus systems does not necessarily have to come directly from actual experience. Only 15.0 percent of residents and 8.2 percent of riders had actually experienced one of the "problems" that the authors asked about during the previous 2 years. Of those residents who said they had experienced crime-related problems, most mentioned robbery (49 percent), vandalism (39 percent), obscene language (28 percent), and panhandling (26 percent) as things that they had actually witnessed or experienced. However, relatively few residents had experienced these problems on or near buses (Table 3). Among bus riders, the top two problems personally experienced were obscene language/disorderly conduct (46 percent) and drunkenness (50 percent).

Surprisingly, perceptions of and experience with "problems" around buses did not vary substantially by demographic groups (Table 4). Generally all residents—black, white, male, female—had the same general perception of bus-related crime problems. However, the differences between riders and nonriders (residents) were marked. Residents generally were three to four times more likely to perceive that these were more of a problem on or near buses. On some problems—obscene language and drunkenness—riders and nonriders had relatively the same responses.

Perceived Safety in Various Circumstances

Both riders and residents were asked how safe they felt in various Greensboro circumstances (Table 5). In this instance, the questionnaires for riders and residents differed. Riders were asked only about circumstances related to buses.

Residents felt safest in familiar and private surroundings such as their home, neighborhoods, and cars (Table 5). Only 2.8 percent of residents felt unsafe while relaxing in their homes; 12.1 percent felt unsafe walking in their neighborhoods; and 18.1 percent unsafe traveling in a car in downtown Greensboro. However, once out of protected spaces (engaged in shopping in suburban malls, waiting at suburban bus stops, riding the bus, walking to catch a bus, or walking downtown) concerns about personal safety among residents increased sharply. Between 24.0 and 32.4 percent of residents felt unsafe in these common, everyday situations. Downtown Greensboro was viewed as particularly unsafe. More than 40 percent of residents felt unsafe in typical downtown-oriented activities, including using bus services in downtown.

Riders, on the other hand, displayed considerably less concern about safety. Only 6 to 7 percent felt unsafe in downtown. Ironically, however, bus riders expressed greater concern about walking to catch a bus in the suburbs (18.3 percent) than about bus use or walking in downtown environments.

More detailed analysis (Table 6) indicated some demographic variations in these patterns. Generally, women expressed greater concern than men (about 15 to 20 percent more than average) for personal safety; white residents expressed greater concern (10 to 15 percent more than average) than blacks; but black bus riders (primarily female) expressed greater concern than white bus riders. However, these effects were mild compared with the primary effect: residents expressed two to five times more concern about personal safety on the bus system as riders did.

Precautions To Protect Against Perceived Risk

To determine the extent to which familiarity with the bus system influenced the types of precautions taken by respondents to these surveys, both surveys asked about particular types of avoidance behaviors, or precautions. Table 7 gives a summary of the results of these questions. In general all types of precautionary behavior were two to three times higher among residents than among transit riders. Of all the precautions listed, more residents avoided people who were drunk (86.1 percent) or strange looking (80.2 percent). More than half of the residents also stated that they avoided

TABLE 4 Percentages of Residents and Bus Riders Personally Witnessing Problems near Buses: Demographic Breakout

	Residents					Riders				
Problem	B	W	M	F	All	B	W	M	F	All
1. Obscene language/disorderly conduct	30.7	25.9	28.4	26.1	26.9	23.8	14.0	25.6	20.6	22.7
2. Drunkenness	----	----	21.8	24.4	23.5	17.9	14.0	16.8	17.7	17.4
3. Panhandling/begging	23.7	22.2	25.0	22.2	23.2	9.2	4.7	9.7	7.7	8.8
4. Vandalism	17.1	18.0	14.1	20.6	18.4	6.4	2.3	5.6	5.9	6.0
5. Robbery	13.6	12.7	12.5	13.7	13.3	2.0	0	.8	2.4	1.6
6. Drug use/sales	18.4	10.5	11.6	14.4	13.4	4.7	0	3.2	4.7	3.8
7. Violent crimes	10.5	6.7	3.4	10.6	8.1	2.8	0	1.6	2.9	2.2
8. Verbal or physical threats	7.9	7.5	3.5	10.1	7.8	4.4	0	5.6	5.9	4.4
n(sample size)	76	161	87	160	247	252	43	125	170	295

B= African American
W= White
M= Male
F= Female

groups of teenagers and travel after dark or alone. Among riders, the top two precautions were avoiding travel after dark (42.6 percent) and strange-looking people (42.3 percent).

With some exceptions, precautionary behavior was similar by race and gender. Generally, women expressed greater precautionary behavior than men, particularly when traveling alone or after dark. Black residents and riders also expressed generally greater precautionary behavior than whites. However, these were relatively minor differences when compared with the fact that two to three times more residents said that they took precautions than did riders.

Exploring Relationship Between Perceived Safety and Ridership

Although the results summarized thus far provided interesting information about why people in Greensboro do or do not ride the bus, they fail to address directly the relationship between perception of safety and ridership. For example, some of the results suggested that not all nonriders felt equally threatened by crime on the bus system. Could it then be assumed that this subgroup of nonriders might be a potential target for a program to increase ridership? More specifically, would it be possible to identify specific concerns or fears that operators might address to entice more nonriders onto the system? In this stage of the analysis the authors sought to determine more specifically the issues, concerns, and demographic and socioeconomic factors that correlated with nonriders' perceptions of safety in or around buses.

To address the specific relationship between safety and ridership, several indexes were created to get an overall feeling of how each citizen felt about personal safety. Specific questions—which appeared on both the residential and rider surveys—were categorized into a cumulative safety index that summarized key aspects of personal safety. Table 8 presents the items in the index. A value of 1 was assigned to each question in each group if the respondent had seen a certain crime, taken a certain precaution, or felt unsafe in a certain location; a value of 0 was assigned if they had not. The sum of all of these values for each respondent and the total of them (cumulative safety index) gives a good description of how safe each respondent perceived their personal environment to be. Thus, the higher the total cumulative safety index, up to a maximum value of 20, the more unsafe that person perceived his or her environment to be. Similar indexes were created for both the rider and the residential survey; however, the authors address only the nonrider/residential group in this analysis. This cumulative safety index ranged from 0 (lowest concern about personal safety) to 20 (highest concern about personal safety). Thus a respondent with a high score of 20 participated in all precautions, believes that all listed criminal activities around bus areas were a problem, and feels unsafe in most situations outside the home. After the cumulative index for residents was completed, it was analyzed for explanations of the variations in the patterns of responses and cumulative scores and to determine what, if any, factors correlated with these cumulative measures of safety. This analysis was performed by using a program called KnowledgeSeeker, which generated classifications of index "trees" for residents.

Figure 1 summarizes the number of respondents in the residential survey (mostly nonriders) who scored at each level (0 to 20) of the cumulative safety index. Of 500 Greensboro residents, only 3.8 percent (n = 19) stated that they had experienced no safety problems and had no concerns about the safety issues listed in the authors' index. Conversely, 0.2 percent (n = 1) said that they had experienced concerns over every situation and taken all the precautions identified in the safety index. Most of the respondents in

TABLE 5 Feelings of Personal Safety in Various Circumstances, Greensboro (%)

	Residents					Riders				
How safe do you feel?	VS	SS	SU	VU	%US	VS	SS	SU	VU	%US
Relaxing you your home	67.8	29.4	2.0	.8	2.8					
Walking in your neighborhood	41.9	46.0	9.0	3.1	12.1					
Traveling in a car in downtown Greensboro	24.5	57.4	14.4	3.7	18.1					
Shopping in a suburban mall area	17.5	57.5	19.5	5.5	24.0					
Stopped at a traffic light in downtown Greensboro	15.9	59.2	18.4	6.4	24.8					
Wainting at a bus stop in Greensboro suburbs	11.0	56.6	25.5	6.9	32.4					
Riding the bus in Greensboro	11.1	57.9	22.8	8.2	30.0					
Walking to catch a bus in Greensboro suburbs	9.8	57.9	25.2	7.2	32.4	37.5	37.5	14.2	4.1	18.3
Walking in a park	15.5	47.2	26.0	11.3	37.3					
Walking in downtown Greensboro	10.8	49.1	28.0	12.1	40.1	41.6	46.7	6.0	1.9	7.9
Transferring at the proposed Depot terminal downtown	7.4	48.0	32.7	12.0	44.7	41.3	45.4	6.3	1.6	7.9
Waiting at a bus stop	6.9	45.4	31.2	16.5	47.7	44.8	45.4	5.4	1.3	6.7
Walking to catch a bus downtown	7.2	46.0	29.7	17.1	46.8					

VS= Very safe
SS= Somewhat safe
SU= Somewhat unsafe
VU= Very unsafe
%US Percent unsafe (SU + VU)

TABLE 6 Feelings of Personal Safety in Selected Circumstances, Greensboro (%)

	Residents					Riders				
Circumstance	B	W	M	F	All	B	W	M	F	All
Walking to catch a bus in Greensboro suburbs	30.0	33.5	27.0	37.6	32.4	20.9	12.5	15.0	22.5	18.3
Transferring buses in proposed downtown terminal at Depot	35.7	48.9	29.7	53.6	44.7	7.3	7.9	4.2	9.9	7.9
Waiting at a bus stop in downtown Greensboro	39.5	50.4	35.3	55.0	47.7	6.5	4.8	4.8	7.3	6.7
Walking in downtown Greensboro	42.5	47.9	30.5	56.1	40.1	8.5	4.8	5.7	10.4	7.9

TABLE 7 Precautions To Protect Personal Safety (% yes)

Precautions	Residents B	Residents W	Residents M	Residents F	Residents All	Riders B	Riders W	Riders M	Riders F	Riders All
Avoid drunken people	82.5	87.3	78.6	90.3	86.1	34.8	30.2	36.0	32.7	34.7
Avoid strange looking people	80.8	80.4	69.7	86.2	80.2	41.7	40.5	47.2	37.3	42.3
Avoid traveling after dark	65.4	54.1	34.1	69.7	56.7	41.1	46.5	45.6	39.2	42.6
Avoid groups of teenagers	61.5	52.0	49.4	57.0	54.2	26.4	18.6	24.0	26.2	25.6
Avoid traveling alone	60.2	46.4	26.0	62.9	50.0	24.8	14.0	18.4	26.8	25.3
Avoid homeless people	50.5	44.4	37.7	49.7	45.3	17.9	15.0	17.9	17.3	17.7
Avoid using bus service	50.0	36.6	33.1	43.2	39.5	14.9	2.3	12.0	13.9	12.9
Avoid people of different races	13.5	14.5	14.1	14.8	14.6	6.8	0.0	4.8	6.6	5.7
sample size	103	350	170	300	470	250	40	123	170	310

TABLE 8 Items in Cumulative Safety Index

Question	Score	
Are these situations a problem around bus areas?	**Yes**	**No**
Obscene language or disorderly conduct	1	0
Panhandling/begging	1	0
Drunkenness	1	0
Vandalism	1	0
Verbal or physical threats	1	0
Drug use/sales	1	0
Robbery	1	0
Violent crimes such as assault, rape, or murder	1	0
***Generally,* do you think you would be very safe, somewhat safe, somewhat unsafe, or very unsafe from crime in the following environment:**	**Very Safe or somewhat safe**	**Somewhat unsafe or very unsafe**
Waiting at a bus stop downtown	0	1
Walking in downtown Greensboro	0	1
Transferring at the proposed terminal at the depot	0	1
Walking to catch the bus in the Greensboro suburbs	0	1
To protect your own safety while out traveling in Greensboro, do you try to avoid?	**Yes**	**No**
Traveling after dark	1	0
Homeless people	1	0
Strange looking people	1	0
Groups of teenagers	1	0
Using the bus service	1	0
Drunken people	1	0
People of different races	1	0
Traveling alone	1	0
All questions listed above	Sum of all scores	

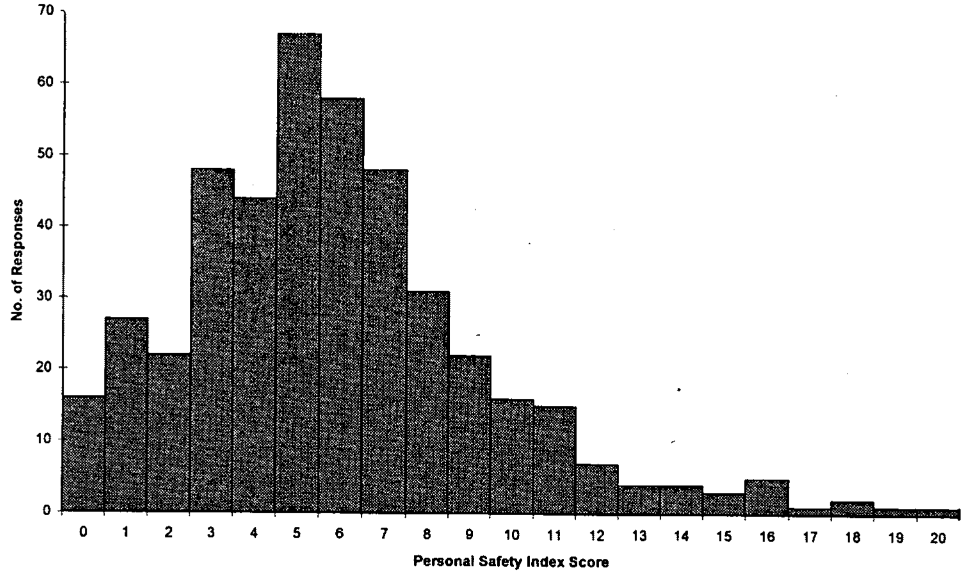

FIGURE 1 Responses for each personal safety index category.

the residential survey scored between 1 and 9 on the cumulative safety index, indicating that most felt relatively safe in the situations described. Overall, the largest clustering of scores ranges from 5 to 7.

Using the search program KnowledgeSeeker, the specific items that most effectively separate those residents who were most concerned and unconcerned about their personal safety were identified. These items are shown as a tree in Figure 2. The critical item—the factor that best predicted how concerned residents were about their own personal safety—was their perception of how safe they would feel "walking to catch a bus downtown."

Further splits in the tree indicated interesting avoidance measures (Figure 2). For example, those people who were generally less concerned about personal safety (felt very safe walking to catch a bus downtown) generally "avoided strange-looking people" for their safety. Those individuals who felt somewhat safe

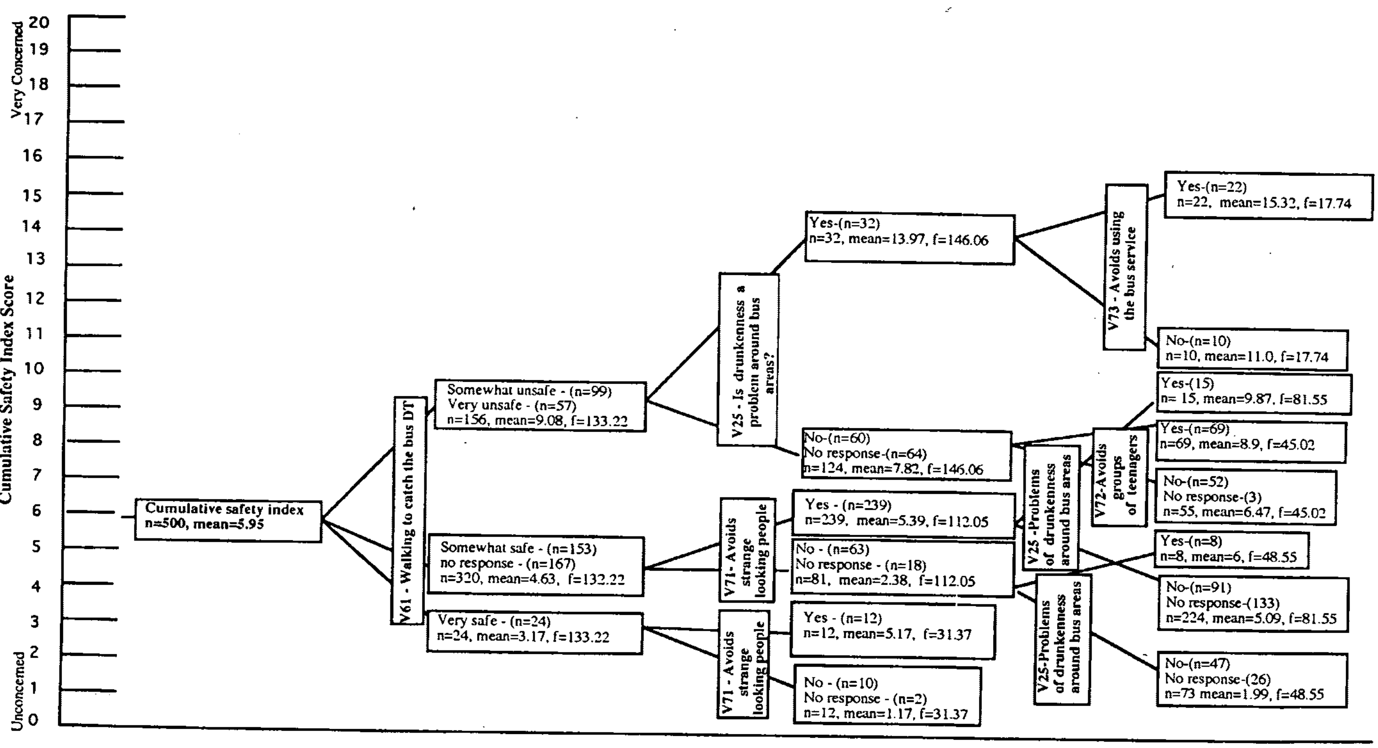

FIGURE 2 Residents' safety concern related to other factors.

when walking to catch a bus in downtown also avoided strange-looking people for their own safety. The single variable that correlated with a high concern and a feeling of being unsafe while walking to catch a bus in downtown was, "is drunkenness a problem around bus areas?" Of the 32 respondents who stated that drunkenness was a problem around bus areas, (n = 22) also stated that they avoid using the bus service for safety concerns.

Analysis of residential cumulative safety indexes using the tree generated by the KnowledgeSeeker strongly suggests that concerns over downtown—specifically, walking to catch a bus downtown—affects how nonriding residents perceive their own personal safety. Since most buses run through downtown along a radial network, residents' safety concerns while walking to catch a bus downtown represent a substantial handicap for the Greensboro bus system. However, even though concern about walking downtown was the critical variable in accounting for the overall safety concerns, residents did not focus on crimes of violence. Instead, drunkenness was the problem that was most correlated with concern about walking downtown. Among residents the relatively "softer" crimes—drunkenness, panhandling, and use of obscene language—appeared to be of more concern to those residents who feel uneasy about walking to catch a bus downtown and thus about their own safety.

SUMMARY, CONCLUSIONS, AND IMPLICATIONS

This analysis of bus patrons (riders) of the Greensboro Transit System and other residents (nonusers) of Greensboro has identified strong similarities with transit use in larger urban settings. Specifically, the authors found that much like transit use in larger urban settings,

- Transit use was relatively low, about 1.6 percent of residents' travel.
- Riders were predominately young, black, and female.
- Riders used the bus system often (5+ days/week), whereas most other residents of the city were rare users of the system.
- Major bus system use was for work and personal business, primarily in early morning and late afternoon hours.
- Riders used the system primarily because they lacked other transportation or had specific destinations or purposes that were accessible by bus.
- Most residents did not use the system because they had a car or other means of transportation and because they perceived that it was not convenient or readily available.

The characteristics of transit riders and nonriders in this relatively smaller system matched those of larger transit systems.

As far as questions about how perceptions of personal safety might affect bus ridership and whether images of crime and safety differed between riders and nonriders, the results were again in line with the authors' expectations. The authors found that fear for personal safety does affect bus ridership in this mid-sized city. They also found that these images did vary between riders and nonriders but that the variations in perceptions of safety and crime among men and women and blacks and whites were not nearly as strong as between riders and nonriders.

Differences between riders and nonriders on matters of personal safety were illuminating. The authors found that

- Only 2.6 percent of residents—nonriders—specifically mentioned personal safety as their reason for not riding.
- A larger proportion of residents (nonriders) than riders (two to four times as many) perceived problems relating to crime and personal safety issues around buses.
- Both residents and riders saw three problems—obscene language and disorderly conduct, drunkenness, and panhandling and beggingas the primary problems related to personal safety on the bus system.
- Residents (but not riders) perceived that vandalism and robbery were associated with the bus system. These views were uniformly held by black and white, male and female residents.
- Few residents or riders (15 and 8.2 percent, respectively) had actually experienced crime-related problems in the past 2 years, and very few respondents though that these experiences were related to buses.
- Residents and riders felt safest in their homes and neighborhoods and while traveling in their cars.
- Residents (more than 40 percent) felt unsafe outside in downtown Greensboro, including when they used the bus system. Bus riders felt much safer in downtown Greensboro using the bus service but relatively less safe walking in the suburbs. With some exceptions, these attitudes did not vary substantially by race or gender.
- More than 80 percent of residents took some precautions to protect their personal safety. The top two precautions mentioned by residents were avoiding people who were drunk or strange looking. More than half of residents also avoided groups of teenagers, travel after dark, and travel alone.
- Generally, women expressed greater precautionary behavior than men, particularly avoiding travel alone or after dark.
- Government policies to increase bus use might best focus on basic service and information provision rather than on personal safety.

In conclusion, buses in Greensboro might appear safer than the community to the nonrider, but in fact the entire community appeared to be relatively fearsome to most of its residents. The impression left with the authors was a city in which residents lived in fear of personal safety but had little direct personal experience with the crime or threats to personal safety that they said they feared. The bus system was not seen as the problem per se; it was perceived as generally safer than the community as a whole. However, it served areas that were perceived as unsafe or having safety problems. Since the system was radial to downtown, and downtown was seen as unsafe by more than 40 percent of residents, it was unlikely that government action to improve service could, in and of itself, significantly increase bus use by the general population unless safety-related perceptions were changed.

If it is assumed that increasing ridership is a primary goal of transit systems, the results described herein offer some possibilities for designing programs to encourage ridership. For example, among the nonriders interviewed in the telephone survey, a sizable group of respondents held attitudes and perceptions of crime indicating that they were relatively less concerned about their own safety moving about the city and felt less concerned about becoming crime victims. This group practiced less avoidance behavior and had lower estimates of overall crime in the city. This group could become a potential source of future riders, representing as it does, a relatively "clean slate," as far as the negative perception of crime on or near the bus. Well-designed advertising and information campaigns could be designed to picture buses as safe from crime, if such programs are coupled with better service, revisions of bus stops, and bus information.

In general, respondents to the phone survey felt negative about downtown Greensboro, perceiving it to be higher in crime problems and opportunities for victimization. However, it is important to distinguish the type of "crimes" about which respondents were most concerned, or which a smaller group had actually experienced. These crimes were activities such as being drunk in public, uttering public obscenities, and panhandling. Technically these activities violate the law, but they fall in the category of "softer" crimes. They are also more likely to occur within the downtowns of American cities; indeed, they are the activities that give many downtowns their negative images. When it is considered that most transit is radial and thus likely to traverse downtowns, it is clear that negative views of downtown are interwoven with negative images of transit. Once again, however, there is a potential remedy involving well-tailored and comprehensive campaigns designed to change images of downtown. If this were coupled with increased presence of public safety officers and stronger efforts to deal effectively with both the social and legal aspects of soft crimes, then perhaps shifts in perception of both downtown and transit would result.

The authors are not suggesting that programs be designed to increase ridership solely by changing perceptions of personal safety downtown. Nor are the authors suggesting that they are easily or quickly accomplished. However, they are suggesting that government agencies focus greater attention on the soft approach to transit safety issues rather than the hardware and high-tech approaches that appear more popular. In addition, programs to change perceptions of downtown and transit safety together would address the concerns of nonriders.

Finally, it appears that many interested parties are willing to collaborate on campaigns to alter negative images of downtown and transit. Downtown employers, retailing, and entertainment establishments, and city and county governments are all concerned about downtowns. Coordinated efforts among these entities and the transit authority over a sustained period might prove effective in bringing the perception of crime in line with the reality of crime both in downtowns and on transit systems.

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