TRANSPORTATION RESEARCH RECORD

No. 1390

Public Transit

Public Transit 1993—Bus, Paratransit, and Ridesharing

A peer-reviewed publication of the Transportation Research Board

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
WASHINGTON, D.C. 1993

Transportation Research Record 1390
Price: $23.00

Subscriber Category
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Library of Congress Cataloging-in-Publication Data
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Public transit, 1993 : bus, paratransit, and ridesharing : a peer-reviewed publication of the Transportation Research Board.
p. cm.—(Transportation research record, ISSN 0361-1981; no. 1390)
ISBN 0-309-05461-3
1. Bus lines—United States—Management—Congresses. 2. Paratransit services—United States—Congresses. 3. Ridesharing—United States—Congresses. I. National Research Council (U.S.). Transportation Research Board. II. Series: Transportation research record ; 1390.
TE7.H5 no. 1390
[HE5623]
388 s—dc20
[388.4'0973]
93-29884
CIP

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Contents

Foreword

This Record presents an important cross section of papers on bus operations, paratransit, and ridesharing research. The papers are based on formal presentations at the 1993 Annual Meeting of the Transportation Research Board. Each paper has been reviewed by peers in the field of transit, both practitioner and academic.

Part 1, Bus Operations, addresses four timely subjects. Khasnabis et al. indicate that bus operations may be improved if intelligent vehicle highway systems signal preemption is fully developed and workable. Yagar suggests that improvements are also achievable if transit is given preference at street intersections. Chang and Lee believe that differing operational requirements affect the choice of fixed- or flexible-route bus systems. Garrity and Eads indicate how transit operators are attempting to implement the Americans with Disabilities Act of 1990 by reviewing bus stop accessibility.

Part 2, Paratransit and Ridesharing, considers five new topics. Teal finds that new technological developments are providing significant opportunity to apply demand responsive transit. The Clean Air Act Amendments of 1990 emphasize employee transportation options. Surveys are essential to organize service, and Beaton et al. indicate that a nonresponse factor must be incorporated. Hartgen and Bullard find that North Carolina has experienced a downward trend in carpool formation and use. Chun explores mechanisms not associated with employer-site programs for reaching potential carpoolers in Southern California, and Christiansen et al. explore such mechanisms for small employer work sites. Collier and Christiansen examine the linkage among commuting behavior, ridesharing, and air quality.

In summary, this Record illustrates the vitality and scope of research activity in bus, paratransit, and ridesharing functions.

PART 1

Bus Operations

Evaluation of the Operating Cost Consequences of Signal Preemption as an IVHS Strategy

SNEHAMAY KHASNABIS, GANGULA V. REDDY, AND
SYED KHURSHIDUL HODA

Signal preemption is a preferential treatment technique to ensure continuous green phases to buses at successive signalized intersections on urban arterials. Although it has been used in Europe with some success, a number of factors have thus far prevented its widespread application in the United States. With development of intelligent vehicle highway systems concepts, there is a growing belief among transit experts about the emergence of signal preemption as a tool for alleviating urban congestion problems. No quick-response tool is available to the transit operator to evaluate the operating cost consequences of signal preemption. A computer simulation model (PREEMPT) is presented to depict the operating cost and ridership consequences of signal preemption. Although no actual preemption device was installed, the model attempts to emulate travel over an urban bus corridor. An elasticity-based demand algorithm built into the model is designed to incorporate the possible effects of improved quality of service and fare changes on operating cost. The model output appears to be reasonable; however, model validation is needed before it can be applied in actual studies.

Delay to buses at signalized intersections on urban arterials makes up a significant fraction of bus trip time. Unlike automobiles, buses cannot be platooned through controlled intersections because of a large variance in the distribution of travel time between different runs. Random variations in the number of passengers boarding and unboarding at bus stops and the resulting differences in the loading and unloading times make the prediction of the exact arrival times of buses at intersections very difficult.

Preemption strategies are designed to provide priority to transit buses over passenger cars. They are preferential treatment devices for buses to ensure continuous green phases at successive signalized intersections on urban arterials, thereby reducing travel time and improving overall speed. The technology includes instrumented buses, transmitters, loop detectors, and a real time control system for estimating arrival times at the intersection and for triggering signal preemption.

If an approaching bus needs and qualifies for preferential treatment, preemption action is initiated. This is accomplished in the form of "green extension" (prolongation of the bus street green phase), "red truncation" (termination of the bus street red phase prematurely), or "red interruption" (injection of a short green phase not continuous with the adjacent green phase). The system logic must recognize that not all buses in need of preemption may qualify for such preferential treatment because of the maximum specified limit of preemption. Thus, when a bus needs preemption but the amount of preemption needed to clear the intersection exceeds the specified maximum, preemption cannot be granted.

In the mid-1970s, experiments were conducted with mixed success in a number of U.S. cities to test various methods of minimizing bus delays at intersections (*1*,*2*). Although specialized signal controls are used widely in Europe today, a number of factors have thus far prevented their widespread applications in the United States. These include the absence of a reliable technology to monitor the arrival of buses (particularly when bus stops are located immediately before the intersection) and to trigger preemption, lack of standards to determine warrants, and inability of the system to prevent inordinate delays to motorists traveling along the cross street. With advances in technology and increased application of intelligent vehicle highway systems (IVHS) concepts, there is growing belief among transit experts about the reemergence of bus preemption as a tool for alleviating urban congestion problems. Under the newly adopted advanced public transportation system program by the federal government, signal preemption is considered a major tool to be tested under the IVHS program in the United States (*3*).

European experience suggests that signal preemption is a viable technology and, if implemented properly, can result in significant reductions in bus delays without greatly affecting cross street traffic. Signals can be actuated by radio, inductive loops on the pavement, or by a combination thereof (*4*). In the past, standard loops reacted to the presence of any vehicle, making the system incapable of distinguishing buses from passenger cars. However, the technique of automatic vehicle classification (AVC) enables the identification of transit vehicles by in-pavement equipment, without the need for an on-vehicle detection system. This feature makes buses distinguishable from other vehicles and candidates for preferential treatment.

Automatic vehicle identification (AVI) technology is considered by many experts as a viable alternative to AVC. The technology consists of a communication link between an onboard transponder and a roadside reader unit. A vehicle identification number (VIN) included in the transponder is decoded whenever the vehicle passes a reader location. The application of AVI technology can be found in the Philips

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Vetag system in the Netherlands for mixed-mode operation; the EVADE system developed by Mullard for emergency vehicles in Northampton, United Kingdom; and the Vehicle Identification and Priority System used for express bus routes between The Hague and Delft in the Netherlands (*5–7*).

The use of license plate scanners developed originally for toll collection has gained some prominence in recent times as a means of selective vehicle identification (*7*). A comparison of license plates read by the system with a set of preferred vehicle records will enable the system to detect the "preferred" vehicles, thus triggering preemption. Unlike AVI or AVC technology, license plate scanners can be used without any on-board equipment, resulting in cost savings. It is not known whether these savings may be offset by the high cost of license plate readers.

Clearly, appropriate technology is available today to implement signal preemption strategies, at least for route level deployment. Unfortunately, no quick-response tool is available to the transit operator that can be used to evaluate the operating cost consequences of signal preemption. For example, increased travel speed may result in reduction of fleet size. It is not known how this reduction might result in reduced operating cost. Similarly, will improved quality of service help the operator gain a larger market share? If so, how might this affect fare box revenue and fleet size? These issues are addressed in the paper.

The purpose of this paper is to present a quick-response tool for analyzing the operating cost consequences of route level preemption. This tool is only for sketch planning purposes and is designed to provide the user with broad information on changes in fleet size, travel time, revenue, and operating cost as a consequence of changes in travel speed attributable to signal preemption. The study methodology does not use preemption development and implicitly assumes that the emerging IVHS technology will enable the deployment of an efficient preemption system. In an earlier paper the authors reported on their initial efforts on this topic (*8*).

METHODOLOGY

A simulation model, PREEMPT, was developed in C language. It can analyze the travel demand, fare box revenue, and operating costs consequences of signal preemption. The software consists of three separate entities that are appropriately linked to provide desired results (Figure 1): (*a*) fleet size, headway, and cycle time; (*b*) operating cost and revenue; and (*c*) elasticity-based demand function.

The model includes a procedure for estimating the number of stops that a bus is likely to skip following a probabilistic approach.

Definitions

The following definitions should be noted:

- Cycle time is the total round-trip time for a vehicle, that is, the interval between two consecutive passes of the same vehicle traveling in the same direction by a fixed point.
- Maximum loading section (MLS) is the line section between two terminal points on which the maximum passenger load occurs.
- Fleet size is the total number of vehicles required to meet the hourly passenger demand at the MLS.

Fleet Size, Headway, and Cycle Time

$$Nv \geq (Dp \times C)/(Vc \times 60) \qquad (1)$$

$$H = C/Nv \qquad (2)$$

$$C = Td + Ts + Tc \qquad (3)$$

where

Nv = number of buses required (fleet size),
Dp = hourly passenger demand at the MLS,
C = cycle time (min),
Td = driving time (min),
Ts = boarding/unboarding time (min),
Tc = layover time (min) (between 2.5 and 5.5 min),
H = headway (min), and
Vc = bus capacity (number of passengers).

Furthermore, driving time, *Td*, is calculated as follows:

$$Td = (60D)/V_{\max} + \{n(V_{\max}/2)\ (5{,}280/36{,}000)\ [(a + b)/60ab]\} \qquad (4)$$

where

D = distance between two terminal points (mi),
$V_{\max}$ = maximum velocity (mph),
n = number of stops at which the bus has to stop (a bus need not stop at all the stops),
a = acceleration rate (ft/sec^2), and
b = deceleration rate (ft/sec^2).

Equation 1 shows that for a given demand *Dp* and bus size *Vc*, the fleet size can be minimized by reducing the cycle time *C*. Furthermore, cycle time, being the total of driving time (*Td*), boarding/unboarding time (*Ts*), and layover time (*Tc*), can be minimized by reducing any of the three components or any combination thereof.

Signal preemption is designed to reduce driving time between two terminals points, thus resulting in a reduction in cycle time, fleet size, and operating cost. Reduced travel time is likely to make the transit system more attractive, thus generating more ridership and higher revenue. PREEMPT can estimate driving times on the basis of (assumed) higher speeds and can recalculate the reduced fleet size and reduced operating costs directly attributable to signal preemption. An elasticity-based demand function that can assess the effect of varying travel times and fare changes attributable to signal preemption is incorporated in the model.

Probability of Skipping a Stop

At the beginning, an assumption must be made on the number of stops of a bus along the route. A bus will typically skip a

TABLE 3 Operating and Fiscal Data for Base Condition and Various Preemption Scenarios, Variable Demand–Variable Fare

Peak Off-Pk. (P, O)	Max. Speed (KM/H)	Fleet Size (No.)	Cycle Time (Min.)	Head-way (Sec.)	Annual O. Cost $(Mill)	Annual Revenue $(Mill)	% Defi-cit	Avg. Speed (KM/H)	EDDPH (No.)	Defi-cit $(Mill)	% Red. in Def.	% Inc. in Sp.
P	40.50	29	33.83	70.00	5.207	4.590	11.860	28.72	2500	0.617	Base	Cond.
O	40.50	14	32.67	140.00				29.76				
P	44.55	23	32.58	85.00	4.344	4.500	-3.58	29.82	2101	-0.156	125.284	8.310
O	44.55	12	29.00	145.00				33.52				
P	48.60	22	31.17	85.00	4.152	4.555	-9.72	31.19	2127	-0.403	165.316	13.767
O	48.60	11	27.50	150.00				35.35				
P	52.65	22	33.00	80.00	4.206	4.553	-8.27	33.13	2126	-0.347	156.240	19.169
O	52.65	11	26.58	145.00				36.56				
P	56.70	21	29.75	85.00	3.961	4.502	-13.65	32.68	2102	-0.541	187.682	20.222
O	56.70	10	25.83	155.00				37.63				
P	60.75	21	28.00	80.00	4.013	4.698	-17.07	34.72	2194	-0.685	211.021	25.845
O	60.75	10	25.00	150.00				38.88				
P	64.80	20	26.67	80.00	3.937	4.570	-16.07	36.45	2134	-0.633	202.593	31.108
O	64.80	10	24.17	145.00				40.22				

EDDPH - Expected demand during peak hour
% Red. in Def. - % Reduction in deficit over base condition
% Inc. in sp. - % Increase in speed over base condition

is the same as Table 2 (corresponding to 60 cents fare), and the remaining rows are for increased fare. Compared with Table 2, increasing speed results in decreasing demand, because of the adverse effect of increased fare on demand.

Figure 2 shows a set of three curves representing a relationship between percentage increase in speed and percentage reduction in deficit. Both of these are computed over the base case (i.e., for the maximum speed of 25 mph). These curves show, for each of the three cases analyzed, the percentage reduction in deficit can be expected as a consequence of increase in speed resulting from signal preemption.

Since the study did not use any actual preemption deployment, the validity of the curves cannot be assessed. The study, however, presents a procedure for quantifying the benefits of preemption. Similar curves can be developed for varying values of elasticity.

The results presented above are to be interpreted only as trends. There are a number of crucial assumptions that may

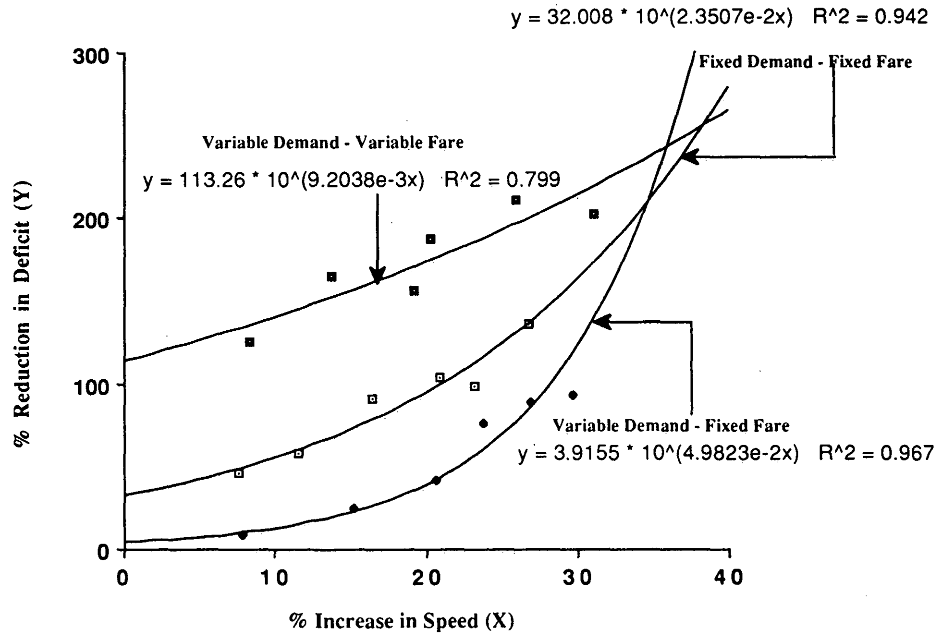

FIGURE 2 Relationship between changes in speed and operating deficit under different demand-fare conditions.

TABLE 1 Operating and Fiscal Data for Base Condition and Various Preemption Scenarios, Fixed Demand–Fixed Fare

Peak Off-Pk. (P, O)	Max. Speed (KM/H)	Fleet Size (No.)	Cycle Time (Min.)	Head-way (Sec.)	Annual O. Cost $(Mill)	Annual Revenue $(Mill)	% Deficit	Avg. Speed (KM/H)	EDDPH (No.)	Deficit $(Mill)	% Red. in Def.	% Inc. in Sp.
P	40.50	29	33.83	70.00	5.180	4.590	11.380	28.72	2500	0.59	Base	Cond.
O	40.50	14	33.83	145.00				28.72				
P	44.55	27	31.50	70.00	4.911	4.590	6.54	30.86	2500	0.32	45.760	7.586
O	44.55	13	31.42	145.00				30.94				
P	48.60	26	30.33	70.00	4.837	4.590	5.11	32.04	2500	0.247	58.136	11.562
O	48.60	13	30.33	140.00				32.04				
P	52.65	25	29.17	70.00	4.643	4.590	1.14	33.32	2500	0.053	91.017	16.356
O	52.65	12	29.00	145.00				33.51				
P	56.70	24	28.00	70.00	4.569	4.590	-0.46	34.71	2500	-0.021	103.559	20.869
O	56.70	12	28.00	140.00				34.71				
P	60.75	24	28.00	70.00	4.599	4.590	0.19	34.71	2500	0.009	98.47	23.096
O	60.75	12	27.00	135.00				36.00				
P	64.80	23	26.83	70.00	4.375	4.590	-4.92	36.22	2500	-0.215	136.44	26.706
O	64.80	11	26.58	145.00				36.56				

EDDPH - Expected demand during peak hour
% Red. in Def. - % Reduction in deficit over base condition
% Inc. in sp. - % Increase in speed over base condition

TABLE 2 Operating and Fiscal Data for Base Condition and Various Preemption Scenarios, Variable Demand–Fixed Fare

Peak Off-Pk. (P, O)	Max. Speed (KM/H)	Fleet Size (No.)	Cycle Time (Min.)	Head-way (Sec.)	Annual O. Cost $(Mill)	Annual Revenue $(Mill)	% Deficit	Avg. Speed (KM/H)	EDDPH (No.)	Deficit $(Mill)	% Red. in Def.	% Inc. in Sp.
P	40.50	29	33.83	70.00	5.207	4.590	11.860	28.72	2500	0.617	Base	Cond.
O	40.50	14	32.67	140.00				29.76				
P	44.55	28	32.67	70.00	5.202	4.637	10.86	29.76	2526	0.565	8.427	7.867
O	44.55	14	29.17	125.00				33.32				
P	48.60	28	30.33	65.00	5.431	4.968	8.53	32.04	2706	0.463	24.959	15.230
O	48.60	15	27.50	110.00				35.35				
P	52.65	29	29.00	60.00	5.630	5.269	6.41	33.52	2870	0.361	41.49	20.637
O	52.65	15	26.25	105.00				37.03				
P	56.70	29	29.00	60.00	5.684	5.537	2.59	33.52	3016	0.147	76.175	23.795
O	56.70	15	25.00	100.00				38.88				
P	60.75	30	27.50	55.00	5.843	5.777	1.12	35.35	3147	0.066	89.303	26.925
O	60.75	15	25.00	100.00				38.88				
P	64.80	30	27.50	55.00	6.033	5.990	0.71	35.35	3263	0.043	93.031	29.695
O	64.80	16	24.00	90.00				40.50				

EDDPH - Expected demand during peak hour
% Red. in Def. - % Reduction in deficit over base condition
% Inc. in sp. - % Increase in speed over base condition

where

Dp = demand,
K = constant,
T = travel time,
p = cost of travel (fare),
y_1 = time elasticity of demand (assumed to be -1.60), and
y_2 = cost elasticity of demand (assumed to be -0.70).

Experience has shown that travel demand varies inversely both with travel time and cost; however, transit demand is more sensitive to travel time than to travel cost. Thus y_1 and y_2 are negative, and the numerical value of y_1 is higher than y_2.

The demand model must be properly calibrated through estimation of the parameter K in Equation 6. The user is prompted to enter the weighted average fare, fare elasticity, and travel time elasticity. The model uses the cycle time computed by the program as a measure of travel time. As the user revisits the program to determine the effect of signal preemption, it will estimate new demand using the constant K along with revised values of travel time and fare. PREEMPT can simulate transit operation under the following three scenarios over and above the base condition:

- Static, for the same demand with different maximum speed, which is assumed to be the result of preemption (fixed demand–fixed fare);
- Dynamic-1, for revised demand resulting from reduced cycle time (consequences of preemption), with an assumed travel time elasticity (variable demand–fixed fare); and
- Dynamic-2, for revised demand resulting from reduced cycle time (result of preemption) and revised fare, with assumed elasticities of travel time and price (variable demands–variable fare).

Operating Cost and Revenue

The cost of the operating services is derived by the fully allocated cost (FAC) method, a technique increasingly applied by transit agencies in which all the cost elements are apportioned into different variables. The FAC model developed for large buses for the regional transit agency in southeast Michigan was used to compile operating cost data (*10*).

$$\text{FAC} = \$1.025X + \$21{,}03Y + \$80{,}516Z \qquad (7)$$

where

FAC = annual fully allocated cost,
X = annual total vehicle miles,
Y = annual total vehicle hours, and
Z = number of buses required to provide peak service.

PREEMPT can develop fare box revenue estimates, given ridership data by fare zones and corresponding fares. This requires information on transit ridership by fare zones. An alternative simplistic technique for computing fare box revenue is also incorporated in the model.

RESULTS

PREEMPT was used to compute operating and fiscal data for three possible scenarios described earlier, for a range of maximum speed values from 25 to 40 mph in increments of 2.5 mph.

The revenue model is based on a fare zone system that requires zonal demand interchange data. For the hypothetical example analyzed in this paper, such zonal data were not available. A simplistic assumption of a constant fare was used, which may have resulted in somewhat unrealistic fare box revenue in the example case. The assumed elasticity values of -1.60 and -0.70 for y_1 and y_2 represent typical values found in the literature.

Input Data

The following input data were used for all three cases:

Item	*Value*
Distance between the two terminal points of the bus route (mi)	10
Peak-hour demand at MLS (passengers per hour)	2,500
Off-peak-hour demand at MLS (passengers per hour)	1,250
Average passengers boarding (passengers per stop)	3
Average passengers alighting (passengers per stop)	3
Acceleration rate (ft/sec^2)	4
Deceleration rate (ft/sec^2)	5
Average boarding time (seconds per passenger)	3
Average alighting time (seconds per passenger)	3
Assumed layover time (min)	5
Bus capacity (excluding standees)	40
Standing capacity (percent)	30
Total number of stops	25
Assumed percentage of stops (anywhere between 70 and 100)	90

Model Output

Table 1 gives the model output under the fixed demand–fixed fare condition. Table 1 indicates that increases in maximum speed result in increases in average speed and reductions in fleet size, cycle time, and operating costs. Since Table 1 is based on constant fare, the revenue remains unchanged. However, since operating cost goes down with increase in speed, there is a gradual reduction in deficit that is directly attributable to signal preemption.

Table 2 (variable demand–fixed fare) represents the situation in which reduced travel time (or improved quality of service resulting from preemption) results in increased travel demand brought about by the elasticity-based demand model. The increase in demand requires a larger fleet size, which results in higher operating cost. Since revenue remains unchanged, higher operating cost results in a larger deficit (compared with Table 1). This feature is somewhat misleading in that improved quality of service appears to contribute to larger deficit! However, the model, by virtue of the demand function, perhaps depicts a reality that increased demand may require larger fleet size and hence higher operating cost.

Table 3 is designed to address the issues raised in Table 2. In this case fare has been increased from 60 to 70 cents and demand is considered to be sensitive to both fare and travel time. To provide a fair comparison, the first row in Table 3

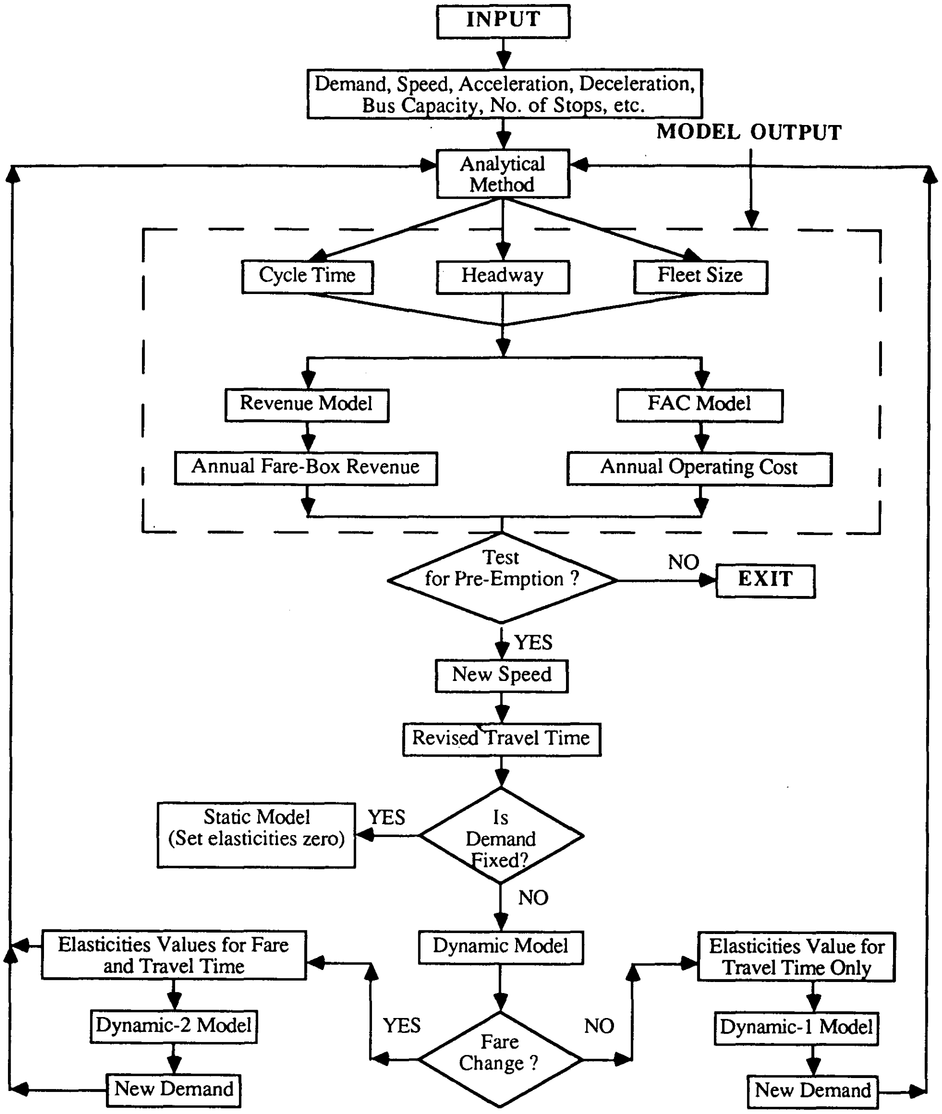

FIGURE 1 Flowchart for PREEMPT software.

stop if there is no boarding or unboarding. For simplicity, the likelihood of a stop being skipped is assumed to be a percentage of the total stops. Once the headway is calculated, the assumption can be checked using the Poisson distribution as follows, where H is headway (min), x' is average arrival rate at a stop (passengers per minute), and y' is average departure rate from a stop (passengers per minute):

$$\text{Probability of skipping a stop} = e^{-(x' + y')H} \tag{5}$$

A review of the preceding equations shows that to calculate H (Equation 2), the cycle time C must be calculated first. Cycle time, however, is a function of driving time Td, which is a function of n, the number of stops where a bus is likely to stop (Equation 4). But one must have a prior estimate of the number of stops likely to be skipped to estimate Td. However, as Equation 5 shows, to estimate the probability of a stop being skipped, the headway H must be known. Thus, a dilemma is presented here in that one requires preknowledge of H to calculate H!

This feature requires the initial assumption of the number of stops where a bus is likely to stop. One can check whether the assumed probability matches the actual probability of skipping stops computed on the basis of headway, passenger arrival rate, and departure rate. The PREEMPT software has a loop operation that facilitates the user in deciding whether (*a*) to check the assumption of stops and (*b*) to recalculate the operating factors in the event the assumed probability of skipping stops does not match the actual probability as calculated above.

Elasticity-Based Demand Function

In Equation 1 the demand Dp is assumed to be fixed under normal conditions. However, reduced travel times resulting from preemption may result in increased demand or larger market capture. Equation 6, which uses the concept of elasticity, was used to estimate the revised demand (*9*):

$$Dp = KT^{y_1}p^{y_2} \tag{6}$$

have an impact on the results. The trends observed in the data presented appear reasonable, indicating that the PREEMPT model is functional. However, further testing of the software and field validation will be needed before it can be applied.

CONCLUSIONS

The purpose of this paper is to demonstrate the use of a computer simulation model, PREEMPT, to depict the operating cost and ridership consequences of traffic signal preemption. Whereas no actual preemption mechanism was installed, the model PREEMPT attempts to emulate the travel time consequences of signal preemption over an urban bus corridor.

The model appears to depict some of the operating and fiscal consequences of signal preemption in a reasonable manner. It computes the operating consequences for given maximum speed values resulting from preemption. A probabilistic approach is incorporated into the model to recognize that a bus may skip certain stops along the route depending on boarding/unboarding demands. An elasticity-based demand algorithm built into the model is designed to incorporate the possible effects of improved quality of service (through preemption) and fare changes on travel demand. Operating cost and revenue consequences are estimated through a FAC model.

No effort was made to validate the model through the actual deployment of preemption hardware, nor was it possible to assess the adverse consequences of preemption for motorists traveling along the cross streets.

ACKNOWLEDGMENT

PREEMPT was developed at Wayne State University as a part of an IVHS educational program funded by the U.S. Department of Transportation through the University of Michigan, Ann Arbor. Matching funds toward the support of graduate students were also made available by the College of Urban, Labor and Metropolitan Affairs, Wayne State University. The authors would like to express their appreciation to the above agencies for their support.

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The authors are fully responsible for the opinions and comments expressed in this paper.

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

Efficient Transit Priority at Intersections

SAM YAGAR

On most transit routes, private vehicles and public transit share a common right-of-way. However, their respective operations are very different from one another, causing an adverse interaction, especially when transit vehicles stop to load and unload passengers on-line at signalized intersections. The severity of traffic delays that are caused when transit operations are ignored by traffic signal control models is illustrated. The impacts on traffic flow caused by transit vehicles stopped to load passengers on-line are illustrated in terms of a typical arrival profile at an intersection, including both cars and a streetcar. It is seen that the streetcar loading operation can significantly reduce capacity and cause delay to both transit and private vehicles, especially when the signal optimization does not take this phenomenon into account. It is shown that, by considering transit loading effects when designing signal timings, delays to both transit and private vehicles can be reduced. Fixed- and real-time methods for providing appropriate transit priority to reduce travel times for transit passengers, and sometimes also to private vehicles, are discussed.

Public transit is used in large metropolitan areas to move large numbers of people to and from the city center without severely affecting the limited urban road capacity. On the one hand, the relatively large buses and streetcars help to achieve this, whereas on the other hand, the nonhomogeneity of operation that they introduce into the traffic operation can disturb the traffic flow.

On most transit routes, private vehicles and public transit share a common right-of-way. However, their respective operations are very different from one another, causing an adverse interaction, especially when transit vehicles stop to load and unload passengers on-line at signalized intersections. Although this interaction is not easily modeled, it cannot be ignored when modeling the operation for traffic signal optimization (*1*). The effects of the traffic impedance caused by the on-line transit loading are bad enough when the loading process is accounted for by the models but can be much worse if the models fail to recognize the loading process, because they then optimize for a pseudooperation, and the signal timings can be meaningless. Therefore, the University of Waterloo is developing models to capture the effects of this transit loading procedure for both fixed- and real-time signal operation. For fixed-time control, some transit modeling enhancements are being made to upgrade the TRANSYT-7F model so that it will represent transit loading phenomena appropriately and thus produce reasonably efficient signal timings (*2*). Also, in the interim, whereas existing operational models cannot properly optimize mixed public and private operation, the Metropolitan Toronto Transportation Department (Metro) and the Toronto Transit Commission (TTC) have been cooperating (*3*) in an attempt to improve the overall people-moving capability of the road system in terms of capacity and delay by use of real-time signal preemption on Queen Street. Metro and TTC are implementing a system of real-time transit priority for streetcars on the Queen Street corridor, and the University of Waterloo is also developing a real-time traffic signal optimization model that is sensitive to transit effects and can give priority to transit when this is desired and appropriate (*4*).

The following sections illustrate the effects of on-line transit loading and briefly describe fixed- and real-time approaches that are being suggested for developing efficient signal timings with due consideration for transit in terms of (*a*) modeling the traffic operations and (*b*) giving appropriate weights to the transit vehicles so that the operator can consciously attempt to minimize either vehicle delay or person delay.

THE QUEEN STREET EXAMPLE

Attempts to apply the bus provisions in the state-of-the-art TRANSYT-7F model to optimize the fixed-time signal operation in Toronto proved unsuccessful. Whereas TRANSYT-7F claims to consider transit effects, it cannot represent the traffic blockage caused when vehicles load on the traveled way. The effects of this will be shown in the section on fixed-time procedures. While stopped, buses cause varying amounts of delay, and streetcars can virtually close an approach if they load from the sidewalk (as is the case at most signalized intersections on Queen Street). Whereas the immediate effects are felt by private vehicles, the capacity reduction is usually also felt by transit vehicles and passengers. The wasted capacity can cause queue buildups, which affect all subsequent vehicles arriving on the shared approaches. These adverse impacts are exacerbated when the optimization models used to select signal timings are unaware of the blockages caused by transit.

The intersection of Queen and Bathurst streets is shown in Figure 1. This intersection serves a demand of 90 streetcars per hour during the peak period, split almost equally among the four approaches. The streetcar and private traffic volumes are shown in Figure 1. With the exception of the northbound approach on Bathurst, there is no refuge from traffic for passengers to access the streetcar. They must walk between the sidewalk and the streetcar, which loads in the median lane. While passengers are getting on and off the streetcar, all traffic in the approach must wait, causing full blockage of the approach.

MODIFICATIONS TO FIXED-TIME PROCEDURES

The TRANSYT-7F model claims to be able to represent the mixed operation of transit vehicles in the traffic stream using

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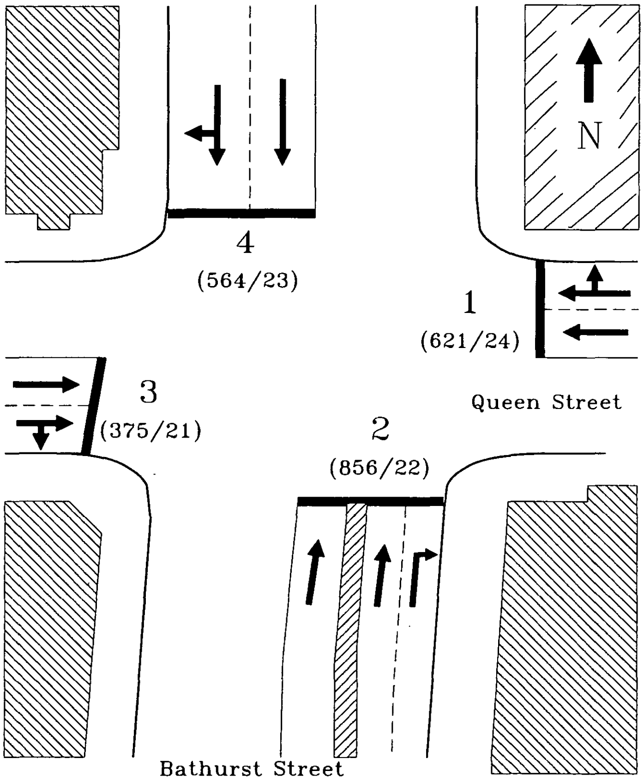

FIGURE 1 Movements and traffic volumes (cars/streetcars) on the four approaches.

a technique introduced in Britain into the TRANSYT/5 version (5). However, this transit provision is not appropriate to normal North American operating conditions. As discussed earlier, when the transit vehicle loads in the traveled right-of-way, it blocks some or all of the road. This is especially critical when a streetcar in the median lane loads passengers from the sidewalk at a signalized intersection, as is the case in the Queen Street corridor in Toronto.

Transit Representation by Current TRANSYT-7F Model

The top portions of Figures 2, 3, and 4 show a typical arrival flow profile for cars in one direction on one approach to a hypothetical intersection if the intersections are closely spaced so that there is no platoon dispersion. In Figures 2, 3, and 4 the normal flow profiles above the time axis represent individual cars *a*, *b*, . . ., *u* in order of arrival, with either 0, 1, or 2 cars moving in each 2-sec time slice. The double X (one above the other) represents the arrival of a streetcar. This arrival profile is assumed to repeat every cycle, in this case every 60 sec.

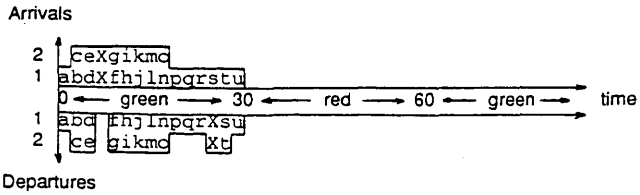

FIGURE 2 Vehicle arrivals and departures for off-line loading of streetcar.

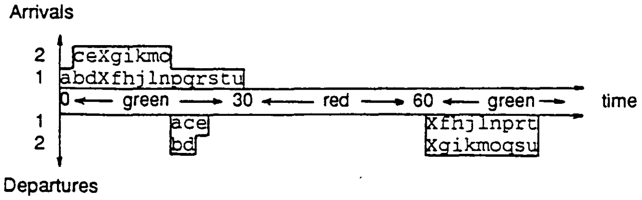

FIGURE 3 Vehicle arrivals and departures when signal settings do not consider streetcar loading effects.

The flow profiles below the time axis represent departures, whose maximum rate of two vehicles per 2-sec time slice represents a saturation flow of 3,600 vehicles per hour of green. For purposes of comparison, Figures 2, 3, and 4 all show the departure profiles for the same vehicles that arrived between $t = 0$ and $t = 30$. Also, Table 1 gives the cumulative departures from $t = 0$ beginning with the same vehicle *a*, which arrived between $t = 0$ and $t = 2$ sec.

For simplicity we suppose that saturation flow equals 3,600 vehicles per hour of green, so that each 2-sec period serves up to two vehicles, and that start-up loss is 1 sec. The typical TRANSYT-type arrival pattern of Figure 2 has 1, 2, 2, 0, 2, 2, 2, 2, 2, 1, 1, 1, 1, 1, and 1 cars arriving in the successive 2-sec periods, for a total of 21 per cycle. In Figures 2, 3, and 4 and Table 1 the streetcars arrive at 8 sec, 68 sec, 128 sec, and so forth. A streetcar displaces about two cars in terms of the saturation flow of the intersection approach.

The simplest way to illustrate and discuss the effects of transit interference is to assume that a streetcar arrives in every cycle at the same relative position within the cycle, as in the top portions of Figures 2, 3, and 4, and that the time taken to load is always the same. Figures 2, 3, and 4 assume a 60-sec cycle (30 green and 30 amber + red) and use the same 18-sec effective loading time.

The departure flow profiles shown on the lower portions of Figures 2, 3, and 4 represent the following cases:

- Figure 2 shows the case where streetcars load off-line and do not hold up private vehicles (cars).
- Figure 3 shows the equilibrium flow profiles that would result when a streetcar loads on-line in each cycle, but TRANSYT-7F sets the traffic signals as if they loaded off-line, as in Figure 2.

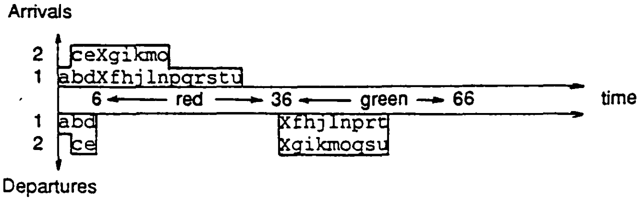

FIGURE 4 Vehicle arrivals and departures when signals are set in response to streetcar loading effects.

TABLE 1 Numbers of Vehicle Arrivals and Departures in Successive 2-sec Intervals

Time (secs)	No. of Arrivals str	car	Cumulative Car Departures for (Fig. 2)	Cumulative Car Departures for (Fig. 3)	Cumulative Car Departures for (Fig. 4)
0		0	0	0	0
2		1	1	0	1
4		3	3	0	3
6		5	5	0	5
8	1	5	5	0	5
10		7	7	0	5
12		9	9	0	5
14		11	11	0	5
16		13	13	0	5
18		15	15	0	5
20		16	16	2	5
22		17	17	4	5
24		18	18	5	5
26		19	18	5	5
28		20	20	5	5
30		21	21	5	5
32		21	21	5	5
34		21	21	5	5
36		21	21	5	5
38		21	21	5	5
40		21	21	5	7
42		21	21	5	9
44		21	21	5	11
46		21	21	5	13
48		21	21	5	15
50		21	21	5	17
52		21	21	5	19
54		21	21	5	21
56		21	21	5	21
58		21	21	5	21
60		21	21	5	21
62		22	22	5	22
64		24	24	7	24
66		26	26	9	26
68	2	26	26	11	26
70		28	28	13	26
72		30	30	15	26
74		32	32	17	26
76		34	34	19	26
78		36	36	21	26
80		37	37	21	26

- Figure 4 shows the equilibrium flow profiles when streetcars load on-line, but this is recognized and taken into account when setting the signal timings.

The flow profiles of Figures 2, 3, and 4 are discussed below.

Streetcar Loads Off-Line (Figure 2)

The signal offset is set to accommodate cars *a*, *b*, . . ., *u* with perfect progression, as TRANSYT-7F would strive to do. TRANSYT-7F would turn the signal green at times 0, 60, 120, and so forth, if other network conditions did not mitigate against this. TRANSYT-7F's timings would not be affected significantly by a loading transit vehicle, since TRANSYT-7F assumes that the transit vehicle travels and loads on a parallel link, entering the shared right-of-way only to preserve its relative position in queue for the signal. Since we have perfect coordination, the vehicles merely pass through the intersection except for the streetcar, which loads off-line from $t = 8$ sec to $t = 24$ sec, at which time it leaves, as shown by the double X. The streetcar takes up both units of capacity and causes car *s* to be delayed and leave with car *t*.

Effects of Transit Loading on the Right-of-Way (Figure 3)

The lower portion of Figure 3 shows what happens to the departure pattern when the signal timings are developed under the incorrect assumption that the transit loading operation does not affect the flow profile. This is explained as follows:

1. The streetcar arrives at 8 sec (upper diagram) but finds a queue in front of it.
2. As will be confirmed by the calculations in Steps 4 and 5 following, the queue in front of the streetcar is not served

until $t = 24$ (after car e has left). The streetcar begins to load at this time and finishes at $t = 42$ (i.e., during the red phase).

3. It then waits for the next green and leaves at $t = 60$ followed by the vehicles that arrived behind it ($f, g, \ldots, u$, with u leaving at $t = 76$ as shown on the bottom portion of Figure 3). Therefore, arrivals $A, B, \ldots, E$ of the next cycle, which arrive between $t = 60$ and $t = 66$ joining the queue behind vehicle u, leave between $t = 78$ and $t = 84$. (The vehicles that arrive in the next cycle, 60 sec after $a, b, \ldots, e$, are labeled using capital letters $A, B, \ldots, E$, respectively.)
4. Since the process is cyclical, vehicles $a, b, \ldots, e$, which arrived one cycle (60 sec) earlier (between $t = 0$ and $t = 6$) would also depart 60 sec earlier than vehicles $A, B, \ldots, E$ of the next cycle (between $t = 18$ and $t = 24$) as shown on the bottom portion of Figure 3.
5. The streetcar that arrived at $t = 8$ would reach the front of the queue after vehicle e departs. This confirms that the streetcar can indeed start loading at $t = 24$.

The equilibrium pattern has each streetcar arriving 8 sec into the green, waiting in queue for 16 sec, then loading into the red phase and leaving at the beginning of the next green.

Recognition and Accommodation of Transit Vehicles (Figure 4)

In Figure 3 we can see that each streetcar queues for 16 sec and then loads for a further 18 sec, thus holding up other traffic for the 18-sec period. If TRANSYT-7F could see this, and if other networkwide factors did not dictate otherwise, TRANSYT-7F would want to turn the signal red at times 8, 68, 128, and so forth so that the streetcars could arrive on a green phase and begin to load immediately but not hold up any other traffic while loading. This would result in the output patterns shown in Figure 4. It would save the streetcar 16 sec of queuing time and reduce the delays to private traffic caused by the loading. Table 1 gives the cumulative vehicle arrivals and the calculated cumulative car departures corresponding to arrivals after $t = 0$. The values given in Table 1 are as follows:

Column	*Value*
1	Time
2	Cumulative streetcar arrivals
3	Cumulative car arrivals
4	Cumulative car departures if the streetcar loads off-line
5	Cumulative car departures if the streetcar loads on-line
6	Cumulative car departures if the traffic signal is adjusted to accommodate the on-line transit loading

The greater the number of vehicles departing at a given time, the better the given tabulated system works. When the cumulative number of vehicles leaving equals 21, all of the vehicles that arrived in the first cycle (between $t = 0$ and $t = 30$) have been served. For the purposes of this illustration, Table 1 was tabulated up to 80 sec, which is enough to show when cumulative departures have reached at least 21 for all cases. Columns 4 and 6 show that some of the second cycle arrivals (after $t = 60$) have already departed by $t = 80$, as indicated in the operations of Figures 2 and 4, respectively.

Discussion of Signal Plans

Off-line loading gives the minimum delay, as would be expected. The earliest departure profiles are in Figure 2, and in Table 1 the highest numbers of departed vehicles at any given time are in Column 4. The same timings would give much poorer performance if the streetcar loads on-line, as is seen in Figure 3 and Column 5 of Table 1. However, if we know the effects on traffic caused by the streetcar loading on-line, we can take this into consideration in setting the signals. The result would resemble Figure 4 and Column 6 of Table 1.

The delays shown in Figure 3 and attributed to TRANSYT-7F are probably realistic, or at least unbiased, representations of how this intersection would perform in a network whose signals were timed using TRANSYT-7F, in view of the fact that TRANSYT-7F does not fully represent the interaction between transit and private vehicles. However, we confess that within a network context we could not likely optimize a given intersection to perform as in Figure 4. Therefore the above estimated saving is really an upper bound. We need a computer model such as TRANSYT-7F to facilitate the analysis of large networks, but the model that is used must recognize the important interactions between transit and private vehicles and be able to represent these effects in its optimization routines. We were able to represent the effects of a streetcar loading in the shared right-of-way with the use of dummy preemptive signals and parallel subnetworks (*6*).

We are currently addressing this model development issue with emphasis on the key problem of transit arrivals in some cycles and not others and the corresponding effects on the periodicity that the TRANSYT model assumes. This involves an adaptation of the TRANSYT-7F model to the more difficult situation of nonperiodic arrivals of streetcars in some cycles and not others (i.e., treating a nonstationary problem with a basically stationary model) (*2*).

REAL-TIME MODELING

In theory, real-time models can accommodate the noncyclical effects of transit vehicles loading on-line more readily than fixed-time models. However, real-time models are relatively new, and have seen very few applications in North America to date. Some of these are described briefly below.

Current Applications in North America

Real-time control is being tested in Canada by applying the SCOOT (*7*) model in Red Deer and Toronto. However, the transit-related problems of TRANSYT-7F also affect SCOOT: it does not recognize the loading effects of transit, and it is basically an evolutionary model of TRANSYT-7F plans that does not respond quickly enough to treat the effects of loading transit vehicles, which occur in some cycles and not others.

OPAC (*8*), a responsive model that uses dynamic programming, is being developed in the United States. However, it is difficult to model transit loading in this type of optimization due to the much larger set of suboptimal states that would have to be considered and stored at each optimization stage.

SCAT (*9*), a real-time model developed in Australia, is being used in a 28-signal network in Oakland County, Michigan. There are plans to add about 80 more signals to the SCAT system. SCAT does not consider mixed transit/traffic operation.

Representing Transit Effects and Providing for Transit Priority

As we said before, Metro and TTC are testing real-time priority on the Queen Street corridor. At the same time the Signal Priority Procedure for Optimization in Real-Time (SPPORT) real-time model (*4*) is being developed to provide real-time signal control under such conditions. It incorporates traffic-responsive signal control methods and takes into account the effects of transit vehicles on traffic flow. Included are facilities to simulate and evaluate its own operation.

Whereas the current version of SPPORT examines only individual intersections, future versions are planned to establish integrated systems of isolated intersections sharing advance information for coordinated real-time network control. For now, it is considered a reasonable approximation to treat intersections with large uncoordinated traffic volumes on competing approaches as isolated intersections.

Development of Signal Timings

SPPORT requires one or more lists of important events or activities, ordered by priority, to which it responds in allocating green time. The higher on the list, the more likely an activity/event is to receive a green phase when requested by the occurrence of that type of event. If there is only one absolute prioritized list of activities/events, SPPORT merely generates the timing sequences rigidly according to detected activities/events, as a preprogrammed traffic cop might do.

However, SPPORT can use the high-speed capability of a computer to generate alternative signal timings and provide respective local optimum solutions for consideration by its own simulation and optimization routines. It generates timing sequences and preevaluates the corresponding traffic operations according to each of any number of alternative priority lists. Each list can be considered as representing the relative priorities accorded by a different traffic expert or traffic cop. Each list has a different order for the events, reflecting its own unique set of relative priorities.

These distinct lists are used to generate alternative traffic signal timing sequences for a time horizon equal to that for which there is advance information on traffic demands. SPPORT preevaluates each of the timing sequences generated from the respective priority lists and dynamically selects the most promising timing plan on-line for immediate short-term application. It then implements the best plan for a renewal period of typically about 5 sec. Then the whole process rolls over for this typically 5-sec period, renewing itself over and over every 5 sec.

The following is an example list of types of events ordered by priority for the simplified case where there are no buses:

1. A streetcar on the main street–peak direction,
2. Serving a queue on the main street–peak direction,
3. A streetcar on the cross street,
4. Serving a queue on the cross street,
5. A streetcar in the main street–off-peak direction,
6. A queue request from the main street–peak direction,
7. Serving a queue in the main street–off-peak direction, and
8. A queue request from the cross street.

SPPORT is traffic-responsive in that it continually detects and uses traffic information to update the current signal plan. This signal plan update is performed approximately every 5 sec, and the SPPORT system is said to function in real-time because it can perform the update within this 5-sec time frame. This system allows for various levels of transit priority (i.e., transit events can be placed at different levels on the priority lists and transit vehicles can be weighted to reflect their occupancy).

Except by direct user request, SPPORT does not give uncontested priority to transit vehicles (i.e., green extension and red truncation are not used to unconditionally favor transit vehicles at the intersection), because this strategy delays private vehicles and can also delay transit vehicles in the long run. SPPORT's method of comparing various schemes for traffic-responsive signal control allows it to give appropriate priority to transit vehicles without hindering the overall performance at the intersection.

For comparing the timings produced by the respective priority lists to determine the most promising signal plan, SPPORT can use any cost function that is given. These are determined by policy. The following are some possible policies that might be considered: minimum vehicle delay, minimum person delay, and total cost (including person delay and operating costs).

Initial tests using an earlier version of the SPPORT model (*4*) have indicated that real-time traffic-responsive transit-priority traffic signal control could be effective.

Representation and Interpretation of Detector Data

Vehicle detectors allow SPPORT to predict vehicle arrivals at the next detector or at the intersection (Figure 5). SPPORT makes such predictions using the detection time, the estimated speed of the vehicle, the distance between the detector most recently activated and the next detector, and the distance between the detector most recently activated and the intersection. For example, a detector installed 500 m upstream of the intersection can provide between 30 and 50 sec of advanced flow information (at an average traffic speed of about 50 km/hr).

When a detector senses a vehicle, it records two pieces of information: the vehicle type (transit, private, or emergency) and the time at which it detected the vehicle.

Representation of the Traffic Interactions of Transit or Emergency Vehicles

Since transit vehicles hold up other traffic while they load and unload passengers, it is necessary to model their operation in the traffic stream. This is discussed below, and SPPORT's methods for representing these effects are described.

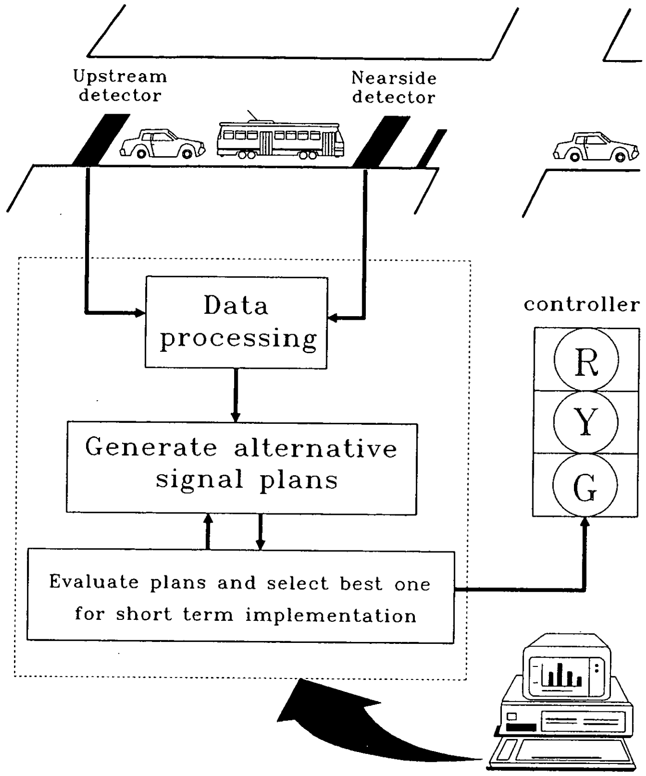

FIGURE 5 **Control structure.**

Typically, a streetcar holds up traffic on all lanes of an approach while loading and unloading, even when the traffic signal is green. This is modeled by reducing the saturation flow to zero while the streetcar loads. A bus blocks the lane in which it is stopped and may disturb traffic in other lanes, especially when loading near an intersection. These disruptions are modeled in SPPORT by temporarily increasing service headways for approaches on which the transit vehicles are loading.

SPPORT estimates the time of departure from the intersection by using a FIFO (first in, first out) queuing model. Departure time is calculated using the status of the traffic signals and the service headway for the approach on which the vehicle is traveling. Service headways are calculated directly from saturation flows.

The user provides saturation flows for each approach, for each type of vehicle, for each of the following situations that may apply at that approach:

1. No transit vehicles are loading,
2. A bus is loading,
3. A streetcar is loading and blocks only part of the approach,
4. Items 2 and 3 both occur, and
5. A streetcar blocks the whole approach (saturation flow = 0).

The time that it takes for transit vehicles to load and unload passengers at a stop is called the dwell time. The user provides SPPORT with a representative (average or median) dwell time for both streetcars and buses.

The appearance of an emergency vehicle greatly disrupts traffic. It is difficult to predict the resultant flow precisely, because individual responses to the approaching emergency vehicle vary. As an initial investigation, an emergency vehicle has been modeled as a nonstop, very high-priority vehicle. The necessary time taken to clear the queue in front of the emergency vehicle is calculated so that the signal can be turned green at an appropriate time in advance of the arrival of the emergency vehicle at the intersection.

Preliminary tests at the critical intersection of Queen and Bathurst streets in Toronto indicate that SPPORT can reduce delays compared with the current fixed-time control and that transit priority measures can reduce person delay even further (*4*).

CONCLUSIONS

Appropriate consideration and modeling of transit operations as they affect traffic flow is critical to providing efficient signal timings. This is especially critical when transit loads passengers on-line at signalized intersections. The use of appropriate models could improve the productivity of an intersection by increasing its throughput and by decreasing total person hours of delay in traffic, compared with the commonly used fixed-time and real-time control models, both of which fail to represent on-line transit loading.

The emphasis of this paper has been on (*a*) describing the adverse effects on traffic caused by transit vehicles loading on-line and (*b*) outlining methods for efficient management of integrated urban traffic systems with transit vehicles that load on the traveled way at signalized intersections.

ACKNOWLEDGMENT

This work was aided by a grant from the Natural Sciences and Engineering Research Council of Canada.

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

Welfare Comparison of Fixed- and Flexible-Route Bus Systems

S. K. JASON CHANG AND C. JIN LEE

Analytic models are used to conduct a comparison under equilibrium demand conditions of welfares for fixed-route conventional bus and flexible-route subscription bus systems for providing feeder services. Optimization models are formulated to maximize welfare for the two feeder bus systems, subject to a break-even constraint. Service zone size, headway, and fare are the decision variables in these analyses. For break-even operation it is shown that the equilibrium demands for the two systems are different due to their specific service attributes and that the optimized fare for flexible-route systems is generally higher than for fixed-route systems. The differences in welfare and fares between the two systems tend to decrease as line-haul distance increases and as service area decreases. The flexible-route bus system is generally favored in cases with lower demand densities, larger service areas, and higher local travel speeds.

Various public transportation modes have their own operating characteristics and thus provide different service qualities. Decision makers face the problem of selecting the best service option for a given environment. Therefore it is desirable to compare the options to determine under what conditions each of these systems is preferable. Full cost comparisons of various public transit systems have been conducted by many researchers and in different ways (*1*–*16*). The general critique for these studies is that they all assume a fixed demand (i.e., demand is perfectly inelastic or insensitive to service quality). This paper attempts to compare fixed- and flexible-route paratransit systems with elastic demand assuming that the bus systems are optimized for the maximum welfare objective, subject to a break-even constraint.

Analytic models have been developed and used in comparing fixed-route conventional bus and flexible-route subscription bus systems (*16*). It was recognized that different demand levels may be generated for service attributes of different systems. A method for comparing the two systems when their service levels generate different passenger volumes was presented in that study. However, that proposed method was still based on the results obtained for the perfectly inelastic demand conditions, and fare was not considered in that analysis.

In this paper, an analytic approach is used to compare the fixed- and flexible-route bus systems under their break-even conditions. The route structures and system characteristics used here are substantially similar to those used by Chang and Schonfeld (*16*), except that elastic demand is considered in this paper. Thus, optimization models with demand elasticity are needed for the comparison. Analytic results for the decision variables (e.g., headway, route spacing, fare) at break-even conditions have been obtained for the fixed-route system (*17*). Therefore, these results are directly used in the comparison. For the flexible-route system, however, since analytic results are difficult to obtain, an algorithm is developed to incorporate the analytic results found for inelastic demand conditions and obtain the equilibrium results for the break-even operation.

BUS SYSTEM CHARACTERISTICS

Figure 1 shows the service areas and their specific route structures for the two feeder systems. The variables and the typical values used in the numerical analyses are defined in Table 1. Basically, the bus systems with either fixed routes or flexible routes are assumed to connect a rectangular area of length L and width W to a major generator (e.g., a transportation terminal or an activity center) that is J km away from that area. Analytic optimization models for these two feeder systems developed in earlier work (*16*,*17*) are applied. These models provide optimized solutions in closed form with perfectly inelastic (fixed) demand, whereas in this paper the two bus systems are designed to operate at break-even and unequal equilibrium demands because of their different service attributes. Route structures and operating characteristics for the two systems are briefly described as follows.

Fixed-Route System

For fixed route systems, the service area is divided into N zones with a route spacing $r = W/N$, as shown in Figure 1a. A vehicle round-trip consists of (*a*) a line-haul distance J traveled at express speed yV from the major terminal to the service area; (*b*) a delivery route L km long traveled at local speed V along the centerline of the zone, stopping for passengers every s km, with an average delay of hours for each stop; and (*c*) reversal of the previous two phases to collect passengers and carry them to the terminal.

Flexible-Route System

The route structure for the flexible-route subscription service is shown in Figure 1b. The service area is divided into N equal zones, each of which has an area $A = LW/N$. This service zone structure is more flexible than that for fixed-route service. Basically, feeder buses travel from the terminal a line-

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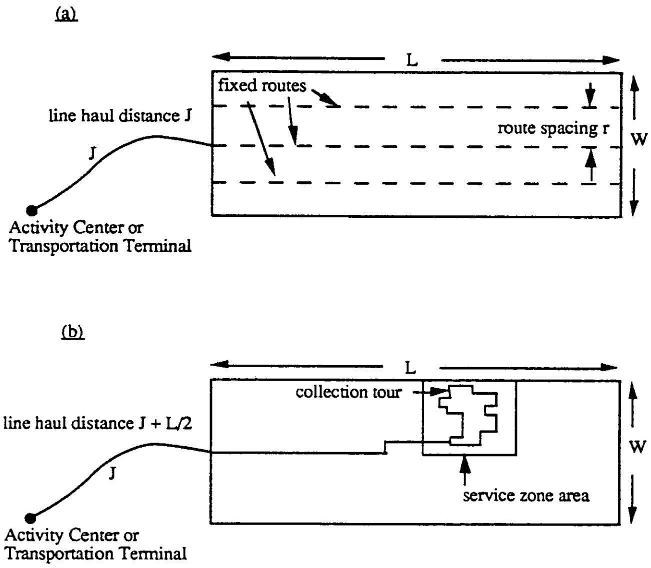


FIGURE 1 (*a*) **Fixed- and** (*b*) **flexible-route feeder bus systems.**

haul distance J and an average distance $L/2$ km at express speed yV to the center of each zone. They collect passengers at their doorsteps through a tour of n stops and length D_c at local speed V. The values of n and D_c are determined using Stein's formula (*18,19*). To return to their starting point, the buses retrace an average of $L/2$ plus J km at yV km/hr. It is assumed that buses operate on preset schedules with variable routing designed to minimize the tour distance D_c, while the tours are routed on a rectangular grid street network. Tour departure headways are assumed to be equal for all zones in the service area. For both service types the average wait time equals a constant factor z_w times the headway h. As in the fixed-route services, vehicle layover time and external costs of bus services are assumed to be negligible.

On the basis of the assumptions that n points are randomly and independently dispersed over an area A and that an optimal traveling salesman tour has been designed to cover these n points, the collection distance D_c in an optimized zone may be approximated by the following result of Stein (*18,19*):

$$D_c = \phi(nA)^{1/2} \tag{1}$$

TABLE 1 Variable Definitions

Symbol	Definition	Baseline value
a	ratio of wait time and headway for flexible-route bus	0.5
A	service zone area (sq. km) = LW/N'	-
B	bus operating cost ($/veh hr)	40.0
C_o	total operator cost ($/hr)	-
D	equivalent avg. round trip distance for fixed-route bus (km) = 2J/Y + 2L/Y	
D_c	distance of one collection tour for flexible-route bus (km)	-
D_L	equivalent line haul distance for flexible-route bus (km) = (L+W)/z+2J/y	
e_p	demand elasticity parameter for fare	0.07
e_v	demand elasticity parameter for in-vehicle time	0.35
e_w	demand elasticity parameter for wait time	0.7
e_x	demand elasticity parameter for access time	0.7
f	fare ($/trip)	-
F	fleet size (vehicles)	-
g	avg. access speed (km/hr)	4.0
G	consumer surplus ($/hr)	-
h	headway (hrs/veh)	-
J	line haul distance (km)	12.8
k	constant in the demand function	-
L	length of service area (km)	6.4
M	avg. in-vehicle travel time (hr)	-
n	number of pickup points in one collection tour	-
N	number of zones	-
q	potential demand density (trips/sq. km/hr)	39.0
Q	demand density function	-
r	route spacing (km) =L/N	-
R	revenue ($/hr)	-
s	bus stop spacing (km)	0.4
u	avg. number of passengers per pickup point	1.2
V	local service speed (km/hr); fixed-route bus=32, flexible-route bus=28	
v	value of in-vehicle time ($/passenger hr)	5.0
w	value of wait time at bus stop ($/passenger hr)	10.0
W	width of service area (km)	4.8
x	value of access time ($/passenger hr)	10.0
y	express speed/local speed ratio	2.0
Y	social welfare ($/hr)	-
z_w	ratio of wait time and headway for fixed-route bus	0.5
z_x	geometric factor for access distance	0.25
ϕ	circuit factor in collection tour	1.15

In Equation 1, ϕ can be considered as the circuit factor and has been estimated to be 0.765 for a Euclidean metric (*18,19*). With a simple strategy to formulate a good traveling salesman tour in zones of irregular shapes, Daganzo (*20*) has also shown that the value of ϕ can be approximated as 0.9 for a Euclidean metric and as 1.15 for a grid network. For a grid network, this circuit factor, which is 1.15, can be directly derived from the value 0.9 for Euclidean metric by an adjusted factor, which reflects the geometric structure of the street network (*20*). Larson and Odoni (*21*) have also discussed applications of Equation 1.

The demand is also assumed to be deterministic and uniformly distributed over time during each specified period. It is also assumed to be uniformly distributed over space within each specified service area. The demand density can be assumed to be obtained from empirical distributions of demand over time, as analyzed in other related works (*16,17,22*). However, in this paper we simply assume a single period with an average demand density for the analysis.

COMPARISON FOR EQUAL DEMAND

The analytic results for the optimal route structures and service headways for the two bus systems have been derived by Chang and Schonfeld (*16*) for perfectly inelastic demand conditions by minimizing the total cost, which includes user cost and operator cost. The closed-form solutions for route spacing, headway, and service zone can be found in related works (*16,23*), and are shown later in Equations 7 to 10 for the flexible-route bus system.

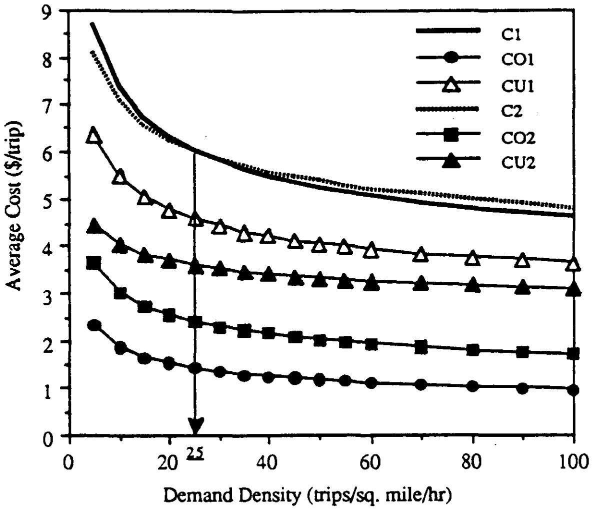
With the analytic average cost functions and the given parameter values for the two systems, we can identify which system is preferable in specific circumstances. For example, the two cost functions in Figure 2 can be used to determine that the flexible-route system is preferable for demand densities below 25 trips per square miles per hour (i.e., 9.8 trips per square kilometer per hour) for the given demand pattern and other assumptions (*16*). Although a comparison for unequal demand has been proposed on the basis of analytic results for inelastic demand conditions, a model with demand elasticity is still needed for comparing route structures, fares, and net social benefits of the two systems at their specific equilibrium demands that might be generated by their different service attributes.

COMPARISON FOR EQUILIBRIUM DEMAND

Objective Function

Various objective functions have been considered appropriate for optimizing bus transit systems (*24*). To compare the two bus systems, maximum social welfare, also known as the net social benefit, is used as the objective function together with a break-even constraint. Denoting G as the consumer surplus, R as the revenue, and C_0 as the operator cost, the break-even problem can be stated as follows:

Maximize $Y = G + R - C_0$ subject to $C_0 - R \leq 0$



Note:
C1 = average cost for fixed-route bus system; = CO1 + CU1
CO1 = average operator cost for fixed-route bus system
CU1 = average user cost for fixed-route bus system
C2 = average cost for flexible-route bus system; = CO2 + CU2
CO2 = average operator cost for flexible-route bus system
CU2 = average user cost for flexible-route bus system

FIGURE 2 System comparison for inelastic demand condition (*16*).

A break-even solution would not exist if the demand function were always below the average operator cost function. That situation would always imply a negative profit. The profitability conditions, which have been evaluated by other studies (*25,26*), are not discussed in this paper. Therefore, it is assumed in the following analysis that the travel demand is sufficient to yield a positive profit in some circumstances for the bus operation considered.

The Lagrange multipliers method is used here for constrained optimization, and the Lagrangian α is formulated as

$$\alpha = G + R - C_0 - \lambda(C_0 - R) \quad (2)$$

where λ is the Lagrange multiplier associated with the break-even constraint. Equation 2 can be rewritten as

$$\alpha = G - (1 + \lambda)(C_0 - R) \quad (2a)$$

which means that solving the problem of maximizing social welfare ($G + R - C_0$) subject to a break-even constraint ($C_0 = R$) is equivalent to solving the problem of maximizing consumer surplus (G) subject to a break-even constraint by defining $1 + \lambda$ as a new Lagrange multiplier.

Linear Demand Function

With a linear demand function in which the demand density is sensitive to various travel time components and fare, analytic results are obtained for fixed-route system under various due to their specific service attributes and that the optimized fare for flexible-route systems is generally higher than for fixed-route systems. Flexible-route bus systems have higher average operator cost (i.e., fare) and lower user costs than fixed-route systems.

The optimality condition that the fare, the average wait cost, and the average access cost are all identical for the fixed-route system at the equilibrium break-even condition does not apply to the flexible-route system, in which the fare (i.e., the average operator cost per trip) is higher than the average wait cost. Sensitivity analyses indicate that the relative advantage of the flexible-route bus system generally increases with lower demand densities, larger service areas, and higher local travel speeds.

In this analysis the two systems are assumed to be mutually exclusive for providing feeder service. Further studies may analyze a system in which both the fixed- and the flexible-route bus services are available and where competition between the two services is allowable. The integration of such systems during various time periods and for different service areas based on their specific characteristics is also worth exploring.

ACKNOWLEDGMENT

This research was supported in part by a grant from the National Science Council of the Republic of China.

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

able assumed values from Table 1. The flexible-route results are obtained by the solution procedures developed above, whereas the fixed-route results are obtained directly by the closed-form solutions given in Table 2. In Figure 3 the two welfare functions intersect at a lone-haul distance of 7 km, where the welfare is \$4,375/hr. Hence, for the given condition implied by the assumed parameter values, a flexible-route bus system is preferable for line-haul distances below 7 km.

This threshold analysis can be designed for other system parameters, such as value of time, travel speed, and service area. The effect of parameter values on the results of threshold analysis is also worth evaluating. In Figure 4, for example, the effects of potential demand density on the threshold values are shown. Figure 4 shows that potential demand density has little influence on threshold values. The threshold line-haul distances are 7, 5, and 4 km for the potential demand densities 39, 98, and 195 trips/sq. km/hr, respectively. Figure 4 also shows that the welfare functions of the two systems become very similar when the potential demand densities decrease.

The threshold analysis has also been applied to determine which system is preferable for various service areas and travel speeds. Figure 5 shows two welfare functions over a range of service areas. These two functions intersect at a service area of 52.5 km^2, where the welfare is about \$6,100/hr. Therefore, given the assumptions implied by the specific parameter values, Figure 5 indicates that the flexible-route bus system is preferable for service areas larger than 52.5 km^2. Since the two welfare functions intersect at such sharp angles, the threshold values of service area are quite sensitive to system parameters. It can also been observed from Figure 4 that the threshold line-haul distances will become more sensitive to system parameters for lower potential demand densities, since the intersection angles tend to sharpen as the potential demand densities become smaller.

Figure 6 shows two welfare functions over a range of local speeds, the bus speed V within the service area. The two functions intersect at a local speed of 33 kph, where the welfare is \$4,100/hr. Therefore, given the parameter values and the implied assumptions, we can say that the flexible-route bus systems are preferable for local speeds above 33 kph.

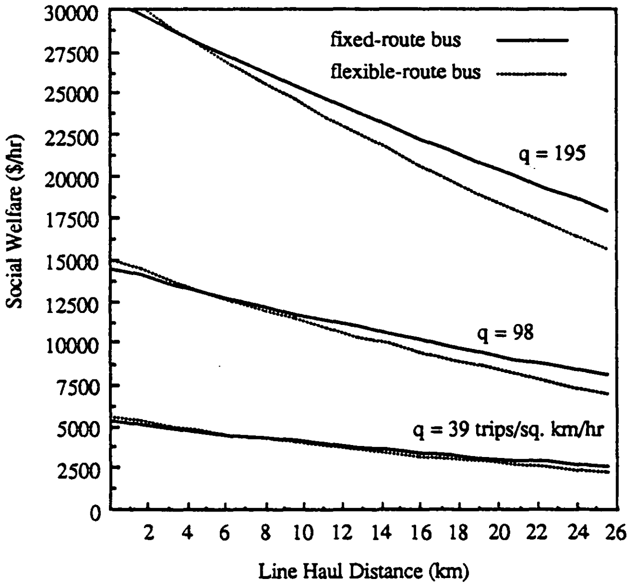

FIGURE 4 Effects of potential demand on threshold line-haul distance.

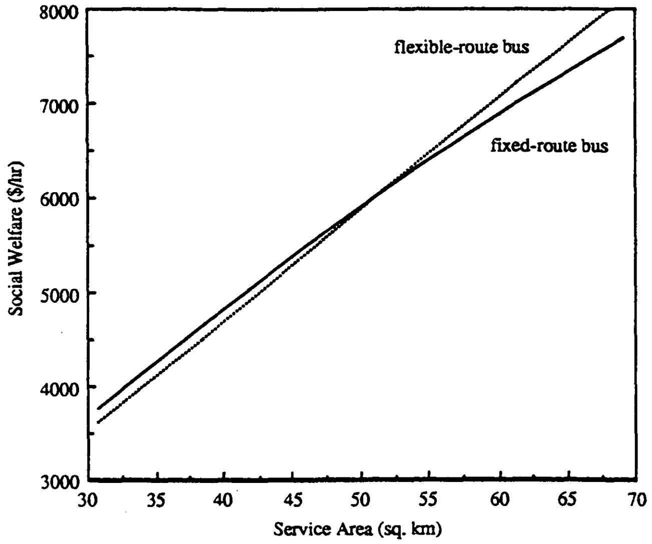

FIGURE 5 Effects of service area on welfare.

CONCLUSION

Welfare relations and results for fixed-route conventional bus and flexible-route subscription bus systems are compared in this paper. Optimization models are formulated for the two feeder bus systems for maximum welfare objective, subject to break-even constraint. The models presented here may be applied in selecting fixed-route or flexible-route bus systems for providing feeder services.

It is shown at the break-even operation that the equilibrium demands and welfare values for the two systems are different

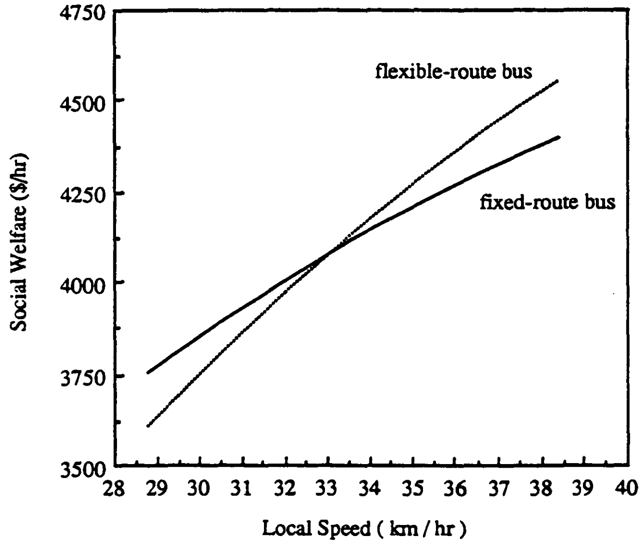

FIGURE 6 Effects of local travel speed on welfare.

where c_o^* is the optimized operator cost per trip for inelastic demand condition and n is the number of stops in one collection tour, approximated as

$$n = \left(\frac{4DB^4L^3Q_i}{awV\phi^2v^3u^5}\right)^{1/6} \tag{10}$$

Step 2. Recalculate demand density Q_i with the demand function:

$$\begin{aligned} Q_i &= F_Q(h_i, M_i, f_i, \cdot) \\ &= q(k - e_w a h_i - e_p f_i - e_v M_i) \end{aligned} \tag{11}$$

Step 3. Set $i = i + 1$ and recalculate the headway, in-vehicle travel time, fare, and demand density using Equations 7 to 11:

$$h_i = F_h(Q_{i-1}, \cdot)$$

$$M_i = F_M(Q_{i-1}, \cdot)$$

$$f_i = F_f(Q_{i-1}, \cdot)$$

$$Q_i = F_Q(h_i, M_i, f_i, \cdot)$$

Step 4. If a stopping rule is satisfied (e.g., $Q_i - Q_{i-1} < \varepsilon$, where ε is a tolerable deviation) STOP, ELSE go to Step 3.

With this solution procedure, the optimal fare f^*, service headway h^*, and the equilibrium in-vehicle travel time M^* for the flexible-route bus system may be obtained. In addition, the equilibrium results of demand Q^*, operator cost C_o^*, revenue R^*, consumer surplus G^*, and social welfare Y^* may be obtained. Comparisons of costs and social welfares for the fixed- and flexible-route bus systems can be conducted accordingly.

NUMERICAL RESULTS

The numerical results for the two bus systems at equilibrium break-even conditions are presented in Table 3 on the basis of the parameter values in Table 1. The optimized fares are \$0.81 per trip and \$1.67 per trip for the fixed- and flexible-route bus systems, respectively. Since the optimized fares for the two systems are obtained at the break-even condition, they are identical to their average operator costs. The two systems differ in their equilibrium demands and social welfare because of their different service attributes. Both the equilibrium demand and the welfare are higher for the flexible-route system than for the fixed-route system. Table 3 shows that the equilibrium demands are 854 and 867 trips per hour for fixed- and flexible-route systems, respectively, with a potential demand of 1,200 trips per hour. The respective welfare values are \$4,458/hr and \$4,470/hr.

The flexible-route bus system has the higher operator cost (i.e., fare) and the lower user cost, which includes wait cost, access cost, and in-vehicle travel cost. At the equilibrium break-even condition the fare, the average wait cost, and the average access cost are all identical for the fixed-route system, but not for the flexible-route system, in which the fare is higher than the average wait cost. These optimality conditions are verified by the numerical results given in Table 3.

TABLE 3 Numerical Results for Equilibrium Break-Even Conditions

Systems	Fixed Route	Flexible Route
Route Spacing (km)	1.30	-
Zone Area (sq. km)	-	4.27
Headway (minutes)	9.6	6.6
Fare (\$/trip)	0.81	1.67
Fleet Size (vehicles)	17	44
Operator Cost (\$/trip)	0.81	1.67
User Cost (\$/trip)	3.56	2.42
Maximum Load (passengers)	37	14
Social Welfare (\$/hr)	4,458	4,470
Equilibrium Demand (trips/hr)	854	867
Potential Demand (trips/hr)	1,200	1,200

The maximum passenger load of 14 for the flexible-route system is significantly different from that of 37 for the fixed-route system. This is due to specific features of flexible-route services, in which passengers pickups in one collection tour should be limited to a certain level. Otherwise, the advantage of this door-to-door service would be reduced by long in-vehicle travel time cost. This analysis suggests that for the flexible-route system it is preferable to use small vehicles to provide door-to-door service. Table 3 also shows that the fleet sizes for the fixed- and flexible-route systems are 17 and 44 vehicles, respectively.

The optimized welfares for the fixed- and flexible-route bus systems may be used to determine which system is preferable under given circumstances. Figure 3 shows a welfare comparison between the two systems. Each has been optimized over a range of line-haul distances for maximum welfare objective subject to the break-even constraint using the reason-

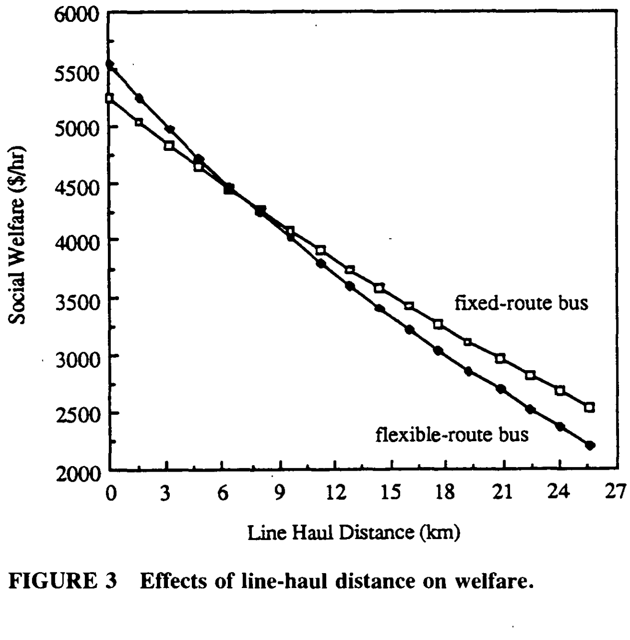

FIGURE 3 Effects of line-haul distance on welfare.

assumptions about the bus route structures (*17,22,27*). This linear demand function is formulated as follows:

$$Q = q(1 - e_w T - e_x X - e_v M - e_p f) \qquad (3)$$

where

q = potential demand density of the bus service;
T = wait time, which may be assumed to be a constant factor z_w (usually $z_w = 0.5$ for uniform passenger arrivals at bus stops) multiplied by the headway h;
X = average access time, which is assumed for the fixed-route system to be $z_w(r + s)/g$, and as defined in Table 1, r is the route spacing, s is the stop spacing, g is the walking speed, and z_x is a geometric access distance factor (usually $z_x = 0.25$ for grid street networks with negligible street spacing) (the average access time is assumed to be zero for the flexible route system, since it provides door-to-door services);
M = average in-vehicle travel time;
f = fare, which is uniform for all passengers; and
e_w, e_x, e_v, and e_p = elasticity factors.

The values of the elasticity factors e_w, e_x, e_v, and e_p are not the actual elasticities in such a linear function. The ratios between the elasticity factors for wait time and fare (e_w/e_p,), for access time and fare (e_x/e_p,), and for in-vehicle time and fare (e_v/e_p) determine the implied values of wait time, access time, and in-vehicle time, respectively.

The analytic results for the optimal route spacing, service headway, fare, consumer surplus, operator cost, and social welfare for the fixed-route systems have been derived by Chang (*17*) and are summarized in Table 2. At equilibrium break-even condition the optimized fare (f^*), the average wait cost (wz_wh^*), and the optimized access cost (xz_xr^*/g) are all identical for the fixed-route system (17, 23).

For the flexible-route system, the objective function can be stated as follows:

$$\text{Maximize } Y = G + R - C_0 \qquad \text{subject to } R - C_0 \leq 0$$

where G, R, and C_0 are the consumer surplus, the revenue, and the operator cost, respectively, and are defined as follows:

$$G = \frac{LWq}{2e_p}(k - e_w z_w h - e_p f - e_v M)^2 \qquad (4)$$

$$R = fLWq(k - e_w e_w h - e_p f - e_v M) \qquad (5)$$

$$C_0 = \frac{LWB}{VAh}\left(D_L + \phi A\sqrt{q(k - e_w a h - e_p f - e_v M)h/u}\right) \qquad (6)$$

TABLE 2 Analytic Results for Break-Even Fixed-Route Bus Systems

Items	Analytic Results
Route Spacing (r^*)	$U\left(\frac{z_w e_w e_p D B g^2}{q V L z_x^2 e_x^2}\right)^{1/3}$
Service Headway (h^*)	$\frac{z_x e_x r^*}{z_w e_w g}$
Fare (f^*)	$\frac{z_x e_x r^*}{e_p g}$
Revenue (R^*) = Operator Cost (C_o^*)	$\frac{z_w e_w W D B g}{z_x z_x V r^{*2}}$
Consumer Surplus (G^*)	$\frac{LWq}{2e_p}\left(k - \frac{3 z_x e_x r^*}{g}\right)^2$
Equilibrium Demand (Q^*)	$LWq(k - 3z_x e_x r^*/g)$

Note: $U = (1 - 3z_x e_x r^*/g)^{-1/3}$

where k is a constant representing a potential demand component insensitive to optimized variables. Obviously, the problem is difficult to solve analytically due to the complexity of Equation 6. A solution algorithm is therefore developed to obtain the equilibrium results. Analytic results for the inelastic demand condition (as shown later in Equations 7 to 10) are used in this algorithm. The solution procedures are stated as follows.

Algorithm

Initialization: Set a demand function $Q_i = F_Q(q, h_i, M_i, f_i)$, where the demand density Q_i is a function of the potential demand q, headway h_i, fare f_i, and in-vehicle travel time M_i. The linear demand function shown in Equation 3, for example, is the demand function used in this analysis, although other nonlinear demand functions may also be considered.

Step 1. Set $i = 0$ and $Q_i = q$, use the following analytic results for inelastic demand condition to obtain h_i and M_i.

$$h_i = F_h(Q_i, \cdot) = \left(\frac{\phi(2B + vun)}{4wa\, Vu^{1/2}Q_i^{1/2}}\right)^{2/3} \qquad (7)$$

$$M_i = F_M(Q_i, \cdot) = \frac{D_L}{2V} + \left(\frac{wa\phi^2u^2}{2(2B + vun)V^2Q_i}\right)^{1/3} \qquad (8)$$

It is implied that all potential trips are captive and thus the bus system is designed on the basis of its total potential demand $Q_i = q$.

Since a break-even constraint is considered, the fare f_i can be obtained using

$$f_i = F_f(Q_i, \cdot) = c_o^*$$
$$= \frac{BD_L}{Vun} + B\left(\frac{4wa\phi^2}{Q_iV^2u(2B + vun)}\right)^{1/3} \qquad (9)$$

Bus Stop Accessibility: A Guide for Virginia Transit Systems and Public Entities for Complying with the Americans with Disabilities Act of 1990

Richard Garrity and Linda L. Eads

The Americans with Disabilities Act of 1990 mandates the elimination of discrimination against persons with disabilities. Compliance with the act requires covered entities to provide transportation services, vehicles, and facilities that are accessible. The compliance activities required on the part of public entities with respect to bus stops and walkways and pathways leading to bus stops are discussed. The Virginia Department of Transportation standards for curb ramps (as recently revised) are discussed. The following technical materials for use in evaluating bus stop accessibility are provided: new bus stop accessibility checklist; existing bus stop accessibility checklist; and accessible site plan for bus stop, pad, and shelter.

The Americans with Disabilities Act (ADA) of 1990 (Public Law 101–336) provides a comprehensive mandate for the elimination of discrimination against persons with disabilities. Accessible public transportation services are a major focus of the regulation. Regulations issued by the U.S. Department of Transportation (USDOT) on September 6, 1991 (49 CFR Part 37), provide that no covered entity shall discriminate against a person with disability in connection with the provision of transportation services. Covered entities include public entities, private entities that provide specified public transportation, and private entities that are not primarily engaged in the business of transporting people but that operate transportation services.

Compliance with the nondiscrimination requirements of the ADA and the regulations requires covered entities to provide for accessible transportation services, vehicles, and facilities. The regulations define the requirements and standards for providing accessible services (49 CFR Part 37), accessible vehicles (49 CFR Part 38), and accessible facilities (49 CFR Part 37, Appendix A). In addition, regulations issued by the U.S. Department of Justice, Office of the Attorney General, apply to places of public accommodation (28 CFR Part 35).

Transportation facilities are defined as all or any portion of buildings, structures, sites, complexes, equipment, roads, walks, passageways, parking lots, or other real or personal property, including the site where the building, property, structure, or equipment is located (49 CFR Part 37.3). Bus stops, bus stop pads, bus stop shelters, and the paths leading to these structures are all covered by the regulation.

PURPOSE

This paper addresses compliance activities required on the part of public entities with respect to bus stops and walkways/pathways leading to bus stops. First, regulatory background is provided for those who may not be familiar with ADA transit facility accessibility guidelines; some of the key issues in bus stop accessibility are also discussed. Second, the Virginia Department of Transportation (VDOT) standards for curb ramps (as recently revised) are discussed. Finally, this paper provides the following technical materials for use in evaluating bus stop accessibility: new bus stop accessibility checklist; existing bus stop accessibility checklist; and accessible site plan for bus stop, pad, and shelter.

REQUIREMENTS COVERING EXISTING AND NEW BUS STOP CONSTRUCTION

49 CFR Part 37, Subpart A—General

There are two key elements of this section. First, USDOT's regulations (49 CFR 37.9, "Standards for accessible transportation facilities") indicate that transportation facilities shall be considered accessible if they meet the requirements of the ADA Accessibility Guidelines, hereafter referred to as ADAAG (49 CFR Part 37, Appendix A).

Second, this section states that public entities shall ensure that the construction of new bus stop pads is in compliance with section 10.2.1(1) of ADAAG, to the extent that construction specifications are within their control.

The USDOT regulations [49 CFR Part 37.9(c)] also state that public entities must exert control over the construction of bus stop pads if they have the ability to do so. The preamble to the regulation recognizes that, in most cases, bus stop design may be out of the control of a transit provider. Where the transit agency does have control, however, it must use its power to ensure that the standards are met.

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49 CFR Part 37, Subpart C—Transportation Facilities

This section governs the construction or alteration of transportation facilities. "New facilities," defined as those facilities where the notice to proceed on construction was provided after January 25, 1992, must be constructed so that the facility is readily accessible to and usable by individuals with disabilities, including individuals who use wheelchairs.

49 CFR Part 37, Appendix A—ADAAG for Buildings and Facilities

Section 10 of ADAAG addresses transportation facilities. Section 10.1 requires that bus stops and bus stop pads comply with Sections 4.1 through 4.35 of the guidelines, which relate to the scope and technical elements of accessibility features and spaces.

Section 10.2.1(1) states that where new bus stop pads are constructed at bus stops, bays, or other areas where a lift or ramp is to be deployed, they must

- Have a firm surface;
- Have a minimum clear length of 96 in. (measured from the curb or vehicle roadway edge) and a minimum clear width of 60 in. (measured parallel to the vehicle roadway) to the maximum extent allowed by legal or site constraints;
- Be connected to streets, sidewalks, or pedestrian paths by an accessible route (as defined in the guidelines); and
- Have a slope, to the extent practical, the same as the parallel roadway.

This section does not require that "pads" be built at bus stops, but it does specify the standards that a bus stop pad must meet if constructed by the covered public entity.

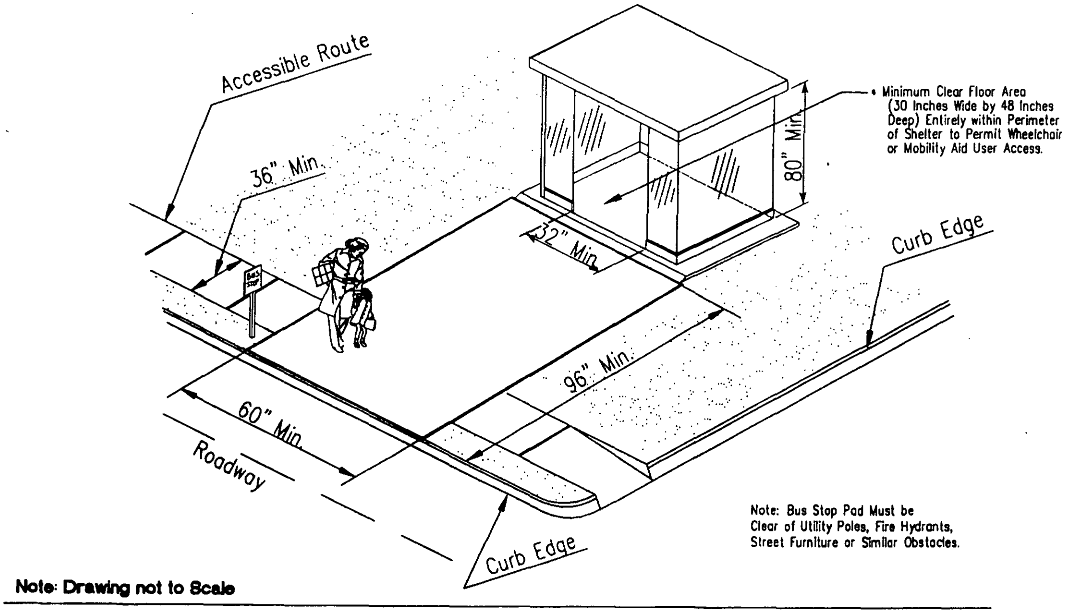
Illustrative ADAAG Compliant Bus Stop Pad and Shelter

Figure 1 shows the ADAAG requirements (minimums) for an accessible bus stop location with a bus stop shelter. In the drawing, a bus stop pad 60 in. wide (measured parallel to the roadway) and 96 in. long (measured from the curb edge) has been constructed. A firm and stable surface (concrete in Figure 1) has been provided. The pad is connected to an accessible route with 36 in., minimum, width.

A bus stop shelter has been placed at the rear of the pad, thereby allowing a wheelchair user to enter from the accessible route. The interior of the bus stop shelter must provide for a minimum clear floor area 30 in. wide by 48 in. deep entirely within the perimeter of the shelter to allow access to the wheelchair or mobility aid user. Entrance to the shelter interior provides for a minimum clear doorway of 32 in. The threshold at the shelter access does not exceed 3/4 in. in height, beveled with a slope no greater than 1:2.

28 CFR Part 35, Subpart D—Program Accessibility

This regulation, promulgated by the U.S. Department of Justice, Office of the Attorney General, is entitled "Nondiscrimination on the Basis of Disability in State and Local Government Services." The rule implements the provisions of Subtitle A of Title II of the ADA, which prohibits discrimination on the basis of disability by public entities. The rule requires that public entities (including local governments) complete a self-evaluation of current services policies and practices, and the effects thereof, that do not or may not meet the requirements of the rule. To the extent that modification of any such services, policies, and practices is required, the public entity must proceed to make the necessary modifications. Subpart B of the rule specifies the general prohibition against discrimination. Subpart D prescribes accessibility re-



• Minimum Clear Floor Area (30 Inches Wide by 48 Inches Deep) Entirely within Perimeter of Shelter to Permit Wheelchair or Mobility Aid User Access.

Note: Bus Stop Pad Must be Clear of Utility Poles, Fire Hydrants, Street Furniture or Similar Obstacles.

Note: Drawing not to Scale

FIGURE 1 Accessible bus stop pad and shelter—minimum ADAAG dimensions.

quirements in existing facilities and the circumstances under which alteration of facilities shall occur. This part requires public entities with 50 or more employees to develop a transition plan if structural changes to facilities will be undertaken to achieve program accessibility. The rule's deadline for completion of structural changes is January 26, 1995, but "in any event as expeditiously as possible."

For public entities that have responsibility or authority over streets, roads, or walkways, the transition plan must include a schedule for providing curb ramps or other sloped areas where pedestrian pathways cross curbs, giving priority to walkways serving entities covered by the act (which include state and local government offices and facilities, transportation, places of public accommodation, and employers), and then walkways serving other areas. Under the Department of Justice regulations, public entities have the option to comply with either the Uniform Federal Accessibility Standards (UFAS) (28 CFR Part 36, Appendix A) or the ADAAG. The regulations differ to some extent in their requirements for accessible routes and curb ramp construction. The sections below provide more details on the ADAAG and UFAS requirements.

PUBLIC ENTITIES, TRANSIT PROVIDERS, AND THE ISSUE OF CONTROL

Most transit agencies do not have legal control over the right-of-way where bus stops are typically located. Under these circumstances, ADA compliance issues would not be a factor for the agency. However, most transit systems in Virginia are owned by a county, city, town, or transit district whose membership consists of local governments. As noted in the summary of applicable Department of Justice regulations, all local governments are required to develop a transition plan for those bus stop boarding areas that are under their control.

Accessible Routes

Regulatory Requirements

Compliance with the bus stop and bus stop pad requirements are not deemed burdensome. Of some concern to public entity transit providers are the provisions for accessible pathways and routes to the bus stop.

The Department of Justice regulations require that public entities ". . . shall operate each service, program, or activity so that the service, program or activity, when viewed in its entirety is readily accessible to and usable by individuals with disabilities."

The regulation does not necessarily require the entity to make all of its facilities accessible to and usable by individuals with disabilities. The regulations allow entities alternative methods for providing accessibility, including delivery of services at alternative sites, reassignment of services to accessible areas, and other methods.

As a practical matter for public transit operators, the fact that the regulations do not require the installation of sidewalks but do require the construction of curb ramps at pedestrian crosswalks presents both an opportunity and some difficulties. First, the opportunity offered to the transit operator is to work with the locality to identify areas along the transit system's routes that are of high priority for construction of accessible routes including sidewalks and curb ramps that access public services. A second opportunity exists to encourage "transit friendly" pedestrian access in developing areas by sharing these guidelines with planners and developers.

The difficulty comes in understanding the technical differences between UFAS (currently in use by many localities and state departments of transportation) and ADAAG and how they affect transportation facilities. The sections below present basic information on the differences between these standards and explain the specific legislative authority over curb ramps delegated to VDOT.

The main differences between ADAAG and UFAS with respect to curb ramps are as follows:

- ADAAG specifies that a detectable warning extending the full width and depth of the ramp be installed; UFAS has no similar requirement.
- ADAAG requires that these detectable warnings consist of raised "truncated domes."
- ADAAG requires that a color contrasting surface be provided on curb ramps, either light-on-dark or dark-on-light.

VDOT Standards for Curb Ramps and Sidewalks

The Code of Virginia (Section 15.1–381) requires that all cities, counties, and towns with streets with curbs construct curb ramps at intersections with pedestrian crosswalks. The law requires that such curb ramps comply with VDOT *Road and Bridge Standards.* Local option, variance, or waiver of these standards is prohibited. Local public works officials should be alerted that the VDOT curb ramp standards were amended in March 1992. The most significant amendment to the standards for curb ramps (Standard CG-12) is the requirement for exposed aggregate finish for detection by visually impaired persons. Instructions are included in VDOT's *Road and Bridge Standards*, Instructional and Informational Memorandum LD-92 (D) 55.3.

VDOT has adopted UFAS as the standard for construction of its facilities. With the Standard CG-12 amendment, the department effectively goes beyond the federal UFAS standard but not to the point of specifically requiring a curb ramp detectable warning surface consisting of "raised truncated domes." VDOT has submitted its CG-12 standard to FHWA under the "equivalent facilitation" process and has received approval. The department is conducting a study through its Research Council to evaluate various methods, including raised dome tiles and concrete stamping machines, for use as detectable warning surfaces for curb ramps.

Design Element Considerations

For accessible routes to bus stops, it is necessary to consider factors and detailed requirements for the following:

- Minimizing travel distance where a separate accessible route is being provided or considered;
- Providing a firm, nonskid surface in wet and dry conditions;
- Avoiding small changes in levels and discontinuities that can cause stumbles or impede a wheelchair or other mobility aid;

Date: ______________________ Site/Stop Inspector: ______________________

Location of Stop: On (Street): At (Street):

Directions: East West North South **Location:** Near Far Middle

SITING (ADAAG 10.2.2)

☐ The site chosen must allow for compliance with the specifications. To the maximum extent practicable, sit must allow for safe deployment of the wheelchair lift.

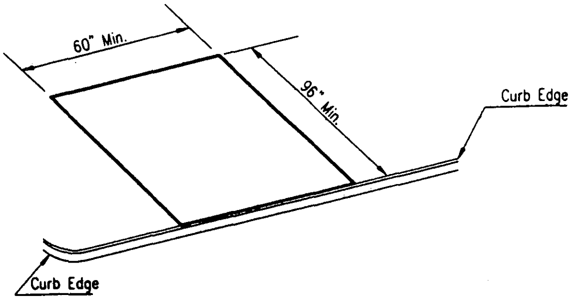
BOARDING AREA

☐ Surface of bus stop pad must have a firm, stable, and slip-resistant surface. Asphalt or concrete are the preferred materials.

☐ The boarding area must have, to the maximum extent practicable or allowed by legal or site constraints, a minimum clear length of 96 inches (measured from the curb edge or vehicle roadway).

☐ The boarding area must have, to the maximum extent practicable or allowed by legal or site constraints, a minimum clear width of 60 inches (measured parallel from the curb edge or vehicle roadway).

Bus Stop Pad Dimensions



☐ The boarding area must be connected to the public way (streets, sidewalks, pedestrian paths) by an "accessible route" (See Accessible Route).

☐ To the extent practicable, the slope of the pad parallel to the roadway must be the same as that of the roadway.

☐ To allow for drainage, the slope of the pad perpendicular to the roadway can be a maximum of 2% (1:50).

Note: Bus stop pads are not required; however, if a pad is constructed it must meet accessibility standards for (1) a firm and stable surface, (2) a minimum clear length (96") and minimum clear width (60"), (3) connection to streets, sidewalks or pedestrian paths by an accessible route; and (4) meet maximum slope requirements (1:50 or 2%).

FIGURE 2 **New bus stop accessibility checklist (new construction).** (*continued on next page*)

ACCESSIBLE ROUTE TO BUS STOP (ADAAG 4.3)

☐ The accessible route must have a clear width of at least 36 inches.

☐ If an accessible route is less than 60 inches clear width (the minimum width needed to allow passage of two wheelchairs), then passing spaces should be constructed at intervals of every 200 feet. A T-intersection of two corridors or walks is an acceptable passing space.

☐ The running slope of the route can be no greater than 1:20 (rise/run). A pathway with a slope greater than 1:20 shall be considered a **ramp**, and shall be subject to additional requirements (see below).

☐ Changes in level along the route cannot exceed 1/2 inch, unless a ramp or lift is provided.

☐ Changes in level along an accessible route between 1/4 inch and 1/2 inch shall be beveled with a slope no greater than 1:2.

☐ The surface of the route must be stable, firm, slip-resistant, and designed to prevent the collection of water.

☐ If gratings are part of the design, elongated spacing must not be greater than 1/2 inch with the long dimension perpendicular to the travel path.

☐ If accessible route crosses a curb, a curb ramp shall be provided.

☐ If curb ramps (curb cuts) are part of the route, they must have a minimum width of 36 inches (excluding flared sides).

☐ If a curb ramp is located where other pedestrians might generate cross traffic and where it is not protected by hand or guard rails, it must have flared sides. The slope of the flared sides can be no more than 1:10.

☐ Curb ramps must have a detectable warning consisting of raised truncated domes 0.9 inches in diameter and 0.2 inches high at a spacing of 2.35 inches center-to-center. The detectable warning must run the full width and depth of the ramp and must contrast visually with adjoining surfaces, either light-on-dark or dark-on-light. The contrasting material must be an integral part of the walking surface.

☐ The slope of the curb ramp cannot exceed 1:12.

☐ The transition from the curb ramp to gutters, streets, or walks must be flush and free of abrupt changes.

☐ Curbs ramps that are built-up cannot project into vehicular traffic lanes.

☐ If an accessible path to a bus stop crosses a roadway with a raised island, the island shall be cut through level with the street or have curb ramps at both sides and a level area at least 48 inches long between the curb ramps in the part of island intersected by the crossing.

FIGURE 2 *(continued)*

SIGNAGE (ADAAG 4.30.2, 4.30.3, and 4.30.5)

☐ If signs are suspended or projected overhead, they must have a minimum clear headroom of 80 inches or a warning barrier.

☐ Letters and numbers must have a width to height ratio between 3:5 and 1:1 and a stroke-width-to-height ratio of between 1:5 and 1:10.

☐ Characters and numbers are to be sized according to the viewing distance from which they are to be read. If signs are suspended or projected overhead, character height must be no less than 3 inches (measured using an uppercase X).

☐ Sign characters and background must be eggshell, matte , or other non-glare finish.

☐ Sign characters and symbols must contrast with their background - either light on dark or dark on light.

SHELTERS (ADAAG 10.2.1(2))

☐ A minimum clear entrance (doorway) of not less than 32 inches must be provided. Dependent upon the design of the shelter, the entrance could be construed to be a part of the "path of travel" and if so, must be a minimum of 36 inches.

☐ A minimum clear floor area measuring 30 inches wide by 48 inches long (deep), completely within the perimeter of the shelter, must be provided.

☐ A wheelchair or other mobility aid user must be able to enter the shelter from the public way and reach the 30 inch by 48 inch clear floor area.

☐ The shelter must be connected to the boarding area by an accessible route (see standards above).

FIGURE 2 *(continued)*

- Selecting a surface material that will meet these criteria;
- Considering long-term affects such as those due to landscaping and tree growth;
- Avoiding placement or carefully considering the effect of any obstacles such as street furniture or gratings on accessible use (maximum signaling size and orientation are stipulated in the regulations);
- Providing passing areas at appropriate intervals (not more than 200 ft) if continuous passage of wheelchairs in either direction (60-in. minimum width) is not possible; and
- Minimizing all gradients wherever possible.

Other factors are as follows:

- Are there at-grade crossings of rail tracks? These are designated as hazardous areas under the regulations and are required to have 36 in. of detectable warning surfaces on either side within the path of travel.
- Sidewalks that are not differentiated from roadways by a curb can be considered hazardous intersections.
- Are bus stop areas provided? Can they meet (where practical) the clear area and other requirements? Do they have to serve buses with both front and rear door lifts?

SUMMARY

ADA requirements related to accessible bus stops will not provide meaningful access to transit services by persons with disabilities if the pathways to these bus stops are not similarly accessible. The preceding discussion of the issues of control and accessible pathway design suggests that the transit provider will need to work cooperatively with both state department of transportation officials and local public works

Date: ____________________ Stop Inspector: ____________________

Location of Stop: On (Street): ______________ At (Street): ______________

Directions: East West North South **Location:** Near Far Middle

1. ACCESSIBLE ROUTE

a. Existing Sidewalk: ____ Yes ____ No
Existing Trail: ____ Yes ____ No
Both Directions from Stop: ____ Yes ____ No

b. If there is <u>no</u> sidewalk, what is the surface of the pathway?

____ grass: ____ hard surface (firmly packed) or ____ soft surface
____ dirt: ____ hard surface (firmly packed) or ____ soft surface
____ gravel: ____ firmly packed surface or ____ loose surface

c. Existing 36" clear width of path: ____ Yes ____ No

d. Path width: ______________ inches

Is a 60" pathway located within 200'? ____ Yes ____ No

e. Are there any changes in level? ____ Yes ____ No

Slope: ____ Level ____ Steep ____ Very Steep

f. Any obstacles or barriers in pathway? ____ Yes ____ No

If yes, explain: ____

____

2. CURB CUTS (Ramps)

a. Location of closest curb cut: ________ feet from bus stop.

b. Curb cut located in both directions from stop? ____ Yes ____ No

c. Curb and gutter: ____ Yes ____ No

d. 36" wide curb cut (exclusive of flared sides): ____ Yes ____ No

FIGURE 3 Existing bus stop accessibility review form. ***(continued on next page)***

e. Flared sides on curb cut? _____ Yes _____ No

f. Ramp Slope: _____ Adequate Slope _____ Slope Too Steep

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3. SURFACE OF STOP LOCATION

_____ concrete: _____ pavement
_____ grass: _____ hard surface (firmly packed) or _____ soft surface
_____ dirt: _____ hard surface (firmly packed) or _____ soft surface
_____ gravel: _____ firmly packed surface or _____ loose surface

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4. LOCATION OF STOP

a. Minimum Clear Length of 96": _____ Yes _____ No
b. Minimum Clear Width of 60": _____ Yes _____ No
c. Connected to an accessible pathway: _____ Yes _____ No
d. Any obstacles that would prevent the proper operation of a lift? _____ Yes _____ No

If yes, what? ____

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5. SHELTER/BENCH

a. Bench: _____ Yes _____ No
b. Shelter: _____ Yes _____ No
c. Windscreen on shelter: _____ Yes _____ No
d. Clear floor within shelter; 30" by 48": _____ Yes _____ No
e. Able to enter the shelter via a public path: _____ Yes _____ No
f. Is the path an accessible route? _____ Yes _____ No
f. Shelter entrance clear width 32" minimum? _____ Yes _____ No

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6. SIGNAGE

a. Sign located at stop: _____ Yes _____ No
b. Sign in accessible format: _____ Yes _____ No

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7. OTHER OBSTACLES OR BARRIERS AT STOP

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8. OVERALL ACCESSIBILITY ASSESSMENT (Field Observation)

_____ Fully accessible
_____ Partially accessible
_____ Not accessible

FIGURE 3 (*continued*)

officials to ensure proper coordination and compliance with the facility requirements associated with the ADA.

USE OF ADA BUS STOP ACCESSIBILITY CHECKLISTS

In Figures 2 and 3, a bus stop accessibility checklist and an existing bus stop accessibility review form are provided for use by local officials in assessing the level of compliance of bus stops within the transit system.

The checklists for new and existing bus stops are based on the ADAAG guidelines. This should be considered when working with a particular locality, because there are differences between ADAAG and UFAS guidelines.

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

PART 2

Paratransit and Ridesharing

Implications of Technological Developments for Demand Responsive Transit

ROGER F. TEAL

The initial development of demand responsive transit (DRT) in the early 1970s was highly ambitious technologically at the time. In fact, many of the early problems with dial-a-ride related to the cost and performance of the computer hardware and software technologies in use 20 years ago. As experience was gained with DRT, the technology for delivering this service became much simpler and relied much less—and in many cases not at all—on computers. In addition, during the past 10 years there has been a strong trend toward advance scheduling of trips on DRT systems, with ridership restricted to certain groups. This represents a fundamental shift away from the original premise of DRT, which was to provide an immediate response local transportation mode for the general public. Recent technological developments offer promise that DRT may be able to return to its technologically sophisticated roots, albeit at a much superior level of performance and cost-effectiveness. The advent of low-cost, high-performance computer hardware, generic data base systems, moderately priced scheduling and dispatching software, mobile computers, inexpensive card readers, hand-held data transfer devices, off-the-shelf automatic vehicle location technology, and electronic mapping software makes possible the development of DRT systems that are much more capable than the typical current system and yet are also relatively affordable. A few systems are now beginning to experiment with these new possibilities. As these efforts, and others, proceed along the development path, how DRT is organized and delivered is likely to change significantly, though gradually, from the current practice.

Demand responsive transit (DRT), when introduced into the public transportation arena in the early 1970s, represented the first major transit service innovation in many decades. Before DRT, public transit consisted of services that were fixed in space and time. Such services require that users find their own means of accessing the transit system, and service is provided only where the fixed routes of the system go. Dial-a-ride—as DRT was then usually referred to—was designed to access users and deliver them to the desired destination. This was to be accomplished by accepting trip requests—consisting of origin point, destination point, and desired pickup or arrival time—from users over the telephone and then dynamically scheduling and routing vehicles to service many of these trip requests simultaneously. The objective was to establish a shared-ride service of moderate productivity providing a level of service substantially better than conventional fixed-route transit, offering the promise that it could compete for some trips being made by automobile.

In addition to representing a radical departure from traditional public transit services, DRT was the first transit innovation premised explicitly on computer technology (*1*). Accordingly, the initial dial-a-ride demonstration projects made extensive use of computer and other electronic technologies to collect and store customer trip information, schedule vehicles for passenger pickups and deliveries, and dispatch trip orders to vehicles. In all likelihood, DRT would not have been conceived without the digital computer, because the complexity of the real-time scheduling and routing problem was such that it was naturally adaptable to computer solution.

The returns from the first few years of DRT implementation called into question the technological basis of this innovation. Whereas computer technologies were an integral element of the most visible projects (Haddonfield, New Jersey; Ann Arbor, Michigan; Rochester, New York; and Santa Clara County, California), it turned out that most DRT systems—at least those that did not have many vehicles—operated successfully with little or no computer technology. Moreover, it quickly became apparent that the cost of full automation of the DRT control system was quite high and not usually cost-effective (*2*). Finally, the market appeal of DRT was far less than had been anticipated. The high level of assumed market penetration, however, had led to estimates of a ridership level that could only be adequately served by full automation of the DRT control system.

Fortunately for the dial-a-ride concept, experience with DRT has demonstrated that it has the capability of being "reinvented" by implementors to adapt to changing needs and circumstances (*3*). The technological underpinning of DRT was one of the first attributes to undergo reinvention. As the evidence accumulated of the lack of need for and relatively unfavorable cost-effectiveness of full computer automation of DRT, there was a strong trend toward technologically simpler DRT systems. Between 1975 and 1990, there were only a handful of attempts to implement technologically sophisticated DRT systems. In fact, the system implemented in Orange County, California, about 1980 is still the most technologically sophisticated DRT system in the country.

Not only did the technology of DRT become much simpler, the very nature of the service also underwent reinvention during the late 1970s and the 1980s. Whereas almost all implementations of DRT before 1975 featured immediate response service for the general public, most DRT systems implemented during the 1980s required users to reserve trips at least 1 day in advance and restricted ridership to certain pop-

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ulation groups (elderly, handicapped, or clients of particular agencies). Advance reservation systems represent a significantly different type of DRT operation from immediate response systems.

As a result of these two major changes in DRT operations over the past 20 years—the virtual abandonment of full automation of the control system and the strong trend toward advance reservation systems—the technology of the typical DRT system today is different from that envisioned by the developers of this mode. With the exception of the Orange County DRT system, the state-of-the-art technology for DRT consists of computerized reservations and scheduling software of varying degrees of sophistication, primarily oriented toward meeting the requirements of advance reservation systems. Whereas the computer hardware is vastly more powerful than that used 20 years ago, the software is better written, and the user interface of the software is undoubtedly easier to work with, in virtually all other respects the typical computerized DRT system today is significantly less technologically sophisticated than the Rochester dial-a-ride system implemented in 1976. [Wilson and Colvin (*4*) describe the computerized DRT system implemented in Rochester.]

Recent developments in hardware and software, however, have created the potential for another technological reinvention of DRT, which would return this mode to its technological roots at a vastly improved level of cost-effectiveness and performance. This potential to "reengineer" DRT, using what is essentially off-the-shelf hardware combined with incremental improvements in software, is stimulating renewed interest in DRT technologies and is the subject of this paper.

TECHNOLOGICAL BASIS OF DRT

The developers of DRT had a vision of how this public transit mode would operate. Figure 1 shows that vision as it existed in the early 1970s. [The source document for the original vision of DRT was prepared by Roos et al. (*1*)].

A computerized reservation, scheduling, and dispatching system served as the heart of the DRT operation. An advanced telephone system would link the patron to an order taker, who would enter the relevant trip information into the computer. A sophisticated algorithm in the computer software would determine the best vehicle to assign to the trip, taking account of the effects of the trip assignment on previously assigned passenger trips. An estimated arrival time for the vehicle would be generated and communicated to the patron. The trip order would be transmitted digitally via radio frequency to the vehicle to which it had been assigned, where it would be displayed on a terminal or printed on a printer. The driver would be able to communicate digitally with the control room through some sort of keyboard/terminal device. It was hoped that an automated system for keeping track of the location of all the vehicles in the system could be included, although the precise nature of the vehicle locator technology was not specified. All information entered into or generated by the system would be stored in data bases, from which it would be retrieved to generate reports on the operation of the system.

To summarize, the originators of DRT anticipated that the following technologies would be used:

- Digital computers,
- Scheduling/dispatching software,
- Digital communication between control room and vehicles via radio frequency,
- In-vehicle video terminals or printers,
- Vehicle location system, and
- Data base systems to store information and generate reports.

This vision of DRT was never fully implemented during the early 1970s, although the Rochester system, which became operational in 1976, contained some form of all of these features except automated vehicle location. The Orange County Transit District's (OCTD's) DRT system, implemented beginning in 1980, also corresponds reasonably well to the above description, again with the exception of automated vehicle location technology. Only the OCTD system is still operational; it represents the sole example in the United States of a DRT system with sophisticated technological features (although the computer hardware and software it uses are antiquated by current standards). The cost of the Rochester project was $3.6 million (not all of this was for technology), and the cost of developing the OCTD system was $2.6 million. In both cases most of the cost was borne by the federal government.

DEEMPHASIS OF AUTOMATED TECHNOLOGIES FOR DRT

There were three primary reasons why the initial vision of DRT did not achieve widespread acceptance. First, it proved much more difficult and expensive to develop the system outlined above than the originators of DRT had anticipated. The computer technology—both hardware and software—of 20 years ago was much less sophisticated and far more costly than that of today. Today, a desktop computer costing less than $3,000 can outperform the computers used in the early DRT systems, which had costs in the range of hundreds of thousands of dollars. Moreover, the software for computerized DRT systems had to be custom developed, including all of the data base and reporting systems.

Second, experience with real DRT systems quickly demonstrated that they did not require sophisticated technologies to operate successfully. Manually scheduled and dispatched systems in Michigan and California achieved system productivities of six to eight passengers per vehicle service hour, which exceeded the productivity level of the computerized systems in Rochester and Haddonfield.

Third, and perhaps most significant, the disappointing ridership of actual DRT systems made technological sophistication both unnecessary and cost-ineffective in most cases. Put simply, DRT did not generate enough demand to warrant systems with large numbers of vehicles, and absent this requirement there was no compelling reason to invest in computer and other electronic technologies for the DRT system (*2*).

As a result of the experiences in the 1970s, the technology of DRT was sharply downscaled. Manual scheduling and dispatching and the use of voice radio communications became the standard mode of operation, and few systems evidenced any serious interest in computerization of functions (other

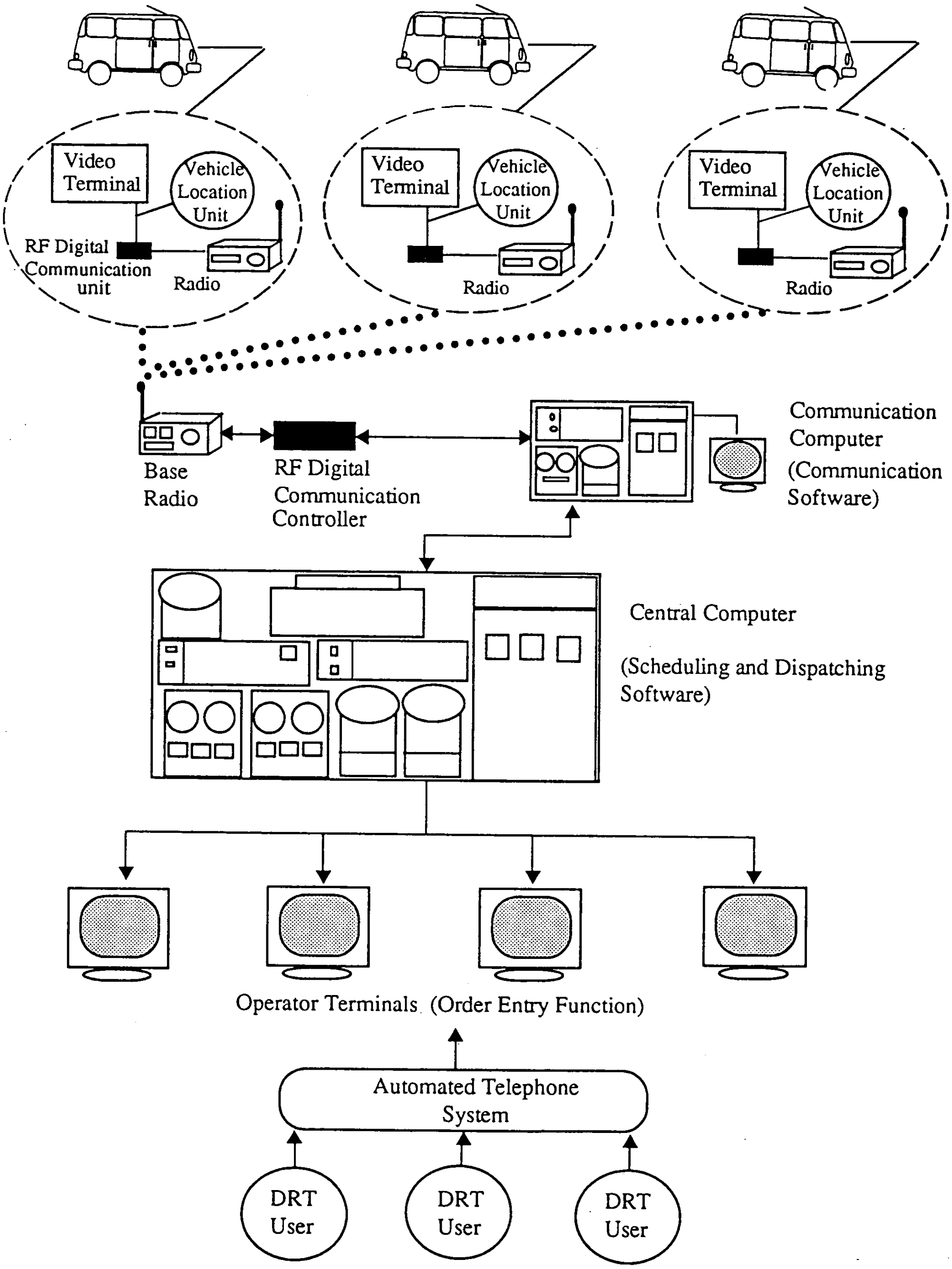

FIGURE 1 Concept of DRT, about 1970.

than record keeping). By the early 1980s, DRT had become a technological backwater.

NEW ERA OF TECHNOLOGICAL POSSIBILITIES

DRT has only recently begun to emerge from its technological hiatus. Several developments during the 1980s proved instrumental in restoring interest in automating various aspects of DRT operations.

One key development was the strong trend toward advance reservation systems. Ironically, even though this represented an abandonment of the cornerstone of the original dial-a-ride concept—real-time scheduling and dispatching of trip requests—it eventually created new needs for computerization. Promoted in part as a method for simplifying the scheduling and dispatching tasks of a DRT operation, advance reservation systems sufficiently complicated the DRT scheduling problem that, beginning in the mid-1980s, DRT systems turned to software solutions. Currently, there appear to be at least 100 to 150 DRT systems that have installed computer software to automate at least some of the reservations/scheduling/dispatching function. None of these systems, however, is as sophisticated as the OCTD DRT operation implemented more than a decade ago.

The second major reason why automation returned to DRT was that it became much more affordable. Because of the revolution in computer hardware that occurred in the 1980s, the hardware platforms for the DRT scheduling packages—primarily personal computers—cost only a small fraction of their 1970 counterparts. Moreover, DRT scheduling software became much less expensive, with some packages selling for as little as $5,000 for a single-computer version and $15,000 for a networked-computer version.

Developments in the taxi industry have also rekindled interest in DRT automation. After resisting computer control of their operations during the 1970s and early 1980s, a number of large taxi companies purchased computerized dispatch systems during the late 1980s. These systems feature automated assignment of vehicles to trip requests, full data base and reporting capabilities, and digital transmission via radio of dispatch messages and other information to in-vehicle data terminals (usually referred to as mobile data terminals). These systems have proven cost-effective in performing the dispatching function for large taxi operations.

Because the algorithms that control the taxi dispatching systems are vastly simpler than those used in DRT scheduling/dispatching software, they are not directly transferable to DRT operations. Nonetheless, they have demonstrated to the paratransit industry the benefits of automation of the control function.

TECHNOLOGIES FOR REENGINEERING DRT

Although the gap between actual practice and current technological possibilities remains large, it has become clear that currently available technologies offer the potential for another major reinvention of DRT. Since the prospective changes involve a return to the original technological foundation of DRT, it is perhaps more accurate to refer to this process as reengineering rather than reinvention. This reengineering holds the promise that large numbers of DRT systems will eventually operate as the developers of this mode intended, but in a much more cost-effective manner than was possible previously.

The most important technologies involved in this reengineering are the following:

- Computer hardware systems,
- Mobile computers and data terminals,
- Radio frequency (RF) data communication devices,
- Vehicle locator devices,
- Mapping software,
- Relational data base systems, and
- Card-based data storage and transfer media.

These seven technologies represent the foundation on which a new generation of DRT systems is likely to be built during the remainder of the 1990s. The key developments in these areas are examined below.

Computer Hardware Systems

Improvements in performance, reductions in cost, and ease of connectivity of computer hardware have become so commonplace that it is easy to underestimate their significance for DRT. The improvement in cost-effectiveness of computer hardware for DRT is in the range of one to two orders of magnitude (i.e., between 10 and 100 times). A handful of networked microcomputers have significantly more computing power than the computer hardware used in the Rochester and OCTD systems and cost less than 10 percent as much. By networking personal computers or UNIX workstations, enough processing power can always be made available for even the most complex scheduling/dispatching software. Consequently, the cost of computer hardware is hardly ever a serious constraint on automation and improved functionality for a DRT system of any significant size.

Mobile Computers and Data Terminals

The revolution in computer hardware has also made possible the development of relatively powerful and inexpensive in-vehicle computers. In-vehicle computers, also referred to as mobile computers, usually have the computing power of at least an 8086-class microprocessor (IBM-XT class) but are approximately the same size as a car radio and can now be purchased for less than $2,000. An in-vehicle computer has a keypad with varying number and types of keys, a display terminal, possibly a built-in or attached printer, and some type of communications link to the central computer, possibly an on-line real-time communications connection. In-vehicle computers can also usually be connected to other devices useful in the transportation environment, such as automatic vehicle location units and card reader/writers.

When used in a DRT application, in-vehicle computers collect data generated in the course of operations, process data, display messages to drivers, and communicate digitally with a host computer system. Mobile computers can also be hand-held computers. Rather than being mounted in the vehicle, a hand-held computer is simply used inside the vehicle. General purpose hand-held computers are currently in the same general price range as in-vehicle computers, although they typically lack connections to printers.

The advantage of mobile computers is that by placing computing power directly in the vehicle, it becomes possible to create more robust and flexible applications—and to support automation of functions without being in continuous communication with the central computer. In an advance reservation DRT system, for example, a day's worth of schedules can be loaded into an in-vehicle computer at the beginning of the day, and the driver can then work independently of central control, except for changes or additions to the schedule, which are communicated via an RF modem link.

Mobile data terminals have also become widely available and are now extensively used in the taxi industry with computerized dispatching systems. Because these data terminals cannot function effectively without being in communication with the central computer, they either contain a built-in RF modem or are connected to such a device. They can hold several dispatching messages and can usually transfer a small amount of data—sometimes no more than a few bytes of status information—from the vehicle to the central computer. Although less powerful and versatile than in-vehicle computers, simple mobile data terminals are nonetheless adequate for certain DRT applications. Moreover, they are less expensive than in-vehicle computers, typically costing less than $1,000 per vehicle.

RF-Based Data Communications Systems

A revolution is occurring in data communications systems with the development of so-called wireless networks. These are data communications systems that rely on RF channels (including cellular radio frequencies) for local transmission rather than physical connections such as telephone lines. For longer-distance transmission, additional telecommunications infrastructure is used. Wireless technologies allow computers and other communication devices to exchange data without being physically connected to a data communications network and thus represent a quantum increase in the flexibility of data communications systems.

The wireless revolution is the backdrop against which developments in RF modem technology are occurring. Currently, RF modems work on the same principle as telephone modems. Digital information (the 0's and 1's of binary data) is encoded by a device into an analog signal, which can then be transmitted over some communications medium to a decoding device at the other end of the channel, where it is converted back into digital data. An RF modem differs from a telephone modem in that it uses radio waves to carry the signal from one location to another. Because RF channels are inherently "noisier" than telephone channels and because of regulatory restrictions on the bandwidth of the carrier signal, RF data transfer is invariably a slower, more error-prone mode of data communication than using telephone lines or direct connections. Most RF modems operate at data transfer rates of 4,800 baud or less, whereas telephone modems typically communicate two to four times faster.

Although RF modems are slower and more expensive than telephone modems (whose price has dropped to below $100 for basic versions), they are becoming increasingly available at reasonable costs and at relatively high speeds. RF modems of 4,800 baud can be purchased for less than $1,000, and RF modems of 1,200 to 2,400 baud cost a few hundred dollars. The latter price is substantially less than the cost of the radio with which the modem will interface. Thus high cost is no longer a serious barrier to the use of digital data communication for DRT operations. In addition, digital cellular modems are just being introduced and may become a viable option if cellular transmission prices are significantly reduced in the future.

Digital RF communication can also occur via digital radios, which are radios with modems integrated into the internal circuitry. Because these radios are specifically designed for digital communication, they are able to operate at higher speeds (e.g., 8,000 baud) than separate RF modems. Their disadvantage is that they cannot also support voice communications, and this limits their utility for DRT applications.

The advantage of digital data transmission for DRT is that it makes much more efficient use than voice transmission of the limited capacity radio channel in transmitting dispatch messages from the control center to the driver in the vehicle. In addition, if real-time data are to be efficiently returned from the vehicle to the control center, digital data communication is essential. The developments in RF technology, therefore, complement developments in the area of mobile computers and data terminals.

Vehicle Locator Devices

The ability to precisely locate vehicles can be of significant value to DRT systems using computerized scheduling and dispatching. By knowing the exact location of vehicles at the time a passenger trip is assigned to a vehicle, it may be possible to improve system productivity, since the proximity of a new trip request to a vehicle's current location on its tour can be better exploited. Until recently, however, vehicle location technology was expensive, and no DRT system to date has used so-called automated vehicle location (AVL) technology.

AVL technology has become markedly more cost-effective during the past year as the result of two developments. First, a U.S. government system of geopositioning satellites (GPSs) has now achieved adequate coverage of the continental United States. This satellite system continuously broadcasts highly accurate positioning information; the satellite signals can be received by any antenna tuned to the appropriate frequencies. The use of these signals is absolutely free, since the U.S. government provides the entire GPS infrastructure.

Second, the cost of GPS receiver units has declined significantly during the past 2 years. A complete GPS receiver can now be purchased for less than $1,000, and a GPS antenna costs an additional $100 to $150. More significantly, circuit board GPS units (which actually contain all of the logic components of the GPS receiver) can now be purchased for $300 to $500 in quantity and can be readily interfaced to an in-vehicle computer to provide the same functionality as a full GPS receiver.

These developments make AVL technology affordable. An end user can purchase the in-vehicle component of AVL technology (mapping and control software is also necessary for a functional system) for only a few hundred dollars per vehicle when the GPS receiver unit is interfaced with other in-vehicle components. AVL systems based on GPS technology have begun to appear in the market and will in all likelihood become the dominant AVL technology. Whereas other types of AVL technology exist, they are usually superseded in accuracy and cost-effectiveness by systems based on GPS.

Mapping Software

An AVL system is only as good as its mapping interface. Simply obtaining locational information is of little value unless that information can be displayed on an electronic map of the service area and manipulated on command. Recent developments in mapping software have fundamentally altered the cost-effectiveness and ease of development of these mapping interface systems, to the pronounced advantage of DRT operations.

As recently as 2 to 3 years ago, most mapping interface systems were expensive pieces of software running on UNIX workstations or minicomputers and using expensive full-function geographic information systems as their foundation. Such systems could cost $100,000 or more when linked to applications software such as computer-assisted dispatch of public safety vehicles.

Today, the leading desktop mapping software package costs approximately $1,000 and runs on a standard personal computer, an application development system can be purchased for a few hundred dollars more, and Census Bureau–based electronic maps of any county in the United States cost less than $250 each. A relatively robust map-based application can be developed in a few weeks by a single programmer. The mapping software can be integrated with a microcomputer-based relational data base system that uses industry standard file formats. Consequently, mapping software and applications using this software have become cost-effective and available to virtually any organization.

For DRT, the major application of electronic mapping is for map-based interfaces to computer-assisted dispatching and for vehicle location systems. The DRT dispatcher can observe on a computer terminal precisely where vehicles are located at the time a trip request is assigned to a specific vehicle.

Relational Data Base Systems

Over the past several years, the data processing industry has adopted a standard data base technology, which now dominates data base systems on computers ranging from mainframes to personal computers. This is the relational data base system. Virtually unused 10 years ago, this technology has rapidly become the industry standard because of its technological superiority over competing types of data base systems.

With relational data base systems, complex applications can be created that are relatively inexpensive. They provide impressive functionality and can be readily modified. Moreover, many applications can be ported to different operating systems and hardware platforms without undue effort and expense. DRT software constructed using these systems as the foundation—as is increasingly done for scheduling/dispatching software—can thus be much more user friendly, powerful, and cost-effective than was the case several years ago. In fact, commercial relational data base systems were simply unavailable at the time of the early implementations of computerized DRT systems.

Card-Based Data Storage and Transfer Technologies

Just as the magnetic stripe card has fundamentally altered the way individuals and businesses conduct their financial transactions, a new generation of card-based technologies may have a similar impact on consumer transactions. This new generation of card technologies is generally referred to under the rubric of "smart cards." This loosely used term refers to three different types of card technologies, all of which can store and alter data but differ in their ability to process the data.

At the low end of the spectrum is the simple stored value memory card. The data on this card can be both read and altered, but the memory is extremely simple and essentially supports a single type of data. In Europe and Japan, telephone stored value memory cards are widely used; a display unit on the telephone indicates to the user how much value remains on the card. The stored value fare cards used in the BART and WMATA rail transit systems are more basic uses of this technology.

More complex memory cards, which can store much more data (as much as 1 megabyte or even more) as well as different types of data on different locations on the card, are available. Such memory cards have been used by public transit operators in Germany to transfer data from the vehicle to the central computer and vice versa.

A "true" smart card is one containing an embedded microprocessor as well as an area for data storage. Most current smart cards can store 8,000 to 24,000 bits (approximately 1,000 to 3,000 bytes) of data. The embedded microprocessor is what gives the smart card its "smarts"—it can actually process data on the card. Relatively few smart card applications to date, however, have taken advantage of this capability, other than for simple functions such as incrementing and decrementing numeric data stored on the card. Another important attribute of the smart card is the additional security it provides compared with conventional magnetic stripe technology—it is possible both to encode data and to prevent unauthorized access to the data on the card.

There are three fundamental advantages of smart cards over magnetic stripe cards. First, they can store much more information. Second, and more important, the data stored on the card can be altered. Third, the embedded microprocessor can execute computer programs that operate on the data on the card.

The major disadvantage of smart cards is their cost. They require a much more complicated card reader—which is actually a reader/writer—than do magnetic stripe cards, and this device costs a few hundred dollars per unit. In contrast, a magnetic stripe card reader costs less than $25. In addition, the cards themselves are relatively expensive, currently costing $6 to $10 each, depending on features (such as photo ID), for cards of 8K to 16K bits.

Because the performance advantage of smart cards comes at a relatively high price, they are likely only to be used where the application requires the ability to alter the data on the card at the time the consumer interacts with the system. To date, the only public transportation implementation of smart cards in the United States has been in the Chicago Transit Authority's paratransit system for the disabled, where smart cards are used both as an electronic purse and to transfer passenger information to hand-held computers in the vehicle.

FUNCTIONAL REQUIREMENTS FOR REENGINEERED DRT SYSTEMS

DRT was developed as a "real-time" public transportation mode, that is, a means of transportation that could be configured at every moment to the requirements of its users. Consequently, the key functional requirements of a reengineered DRT system revolve around real-time assignment of vehicles to trip requests and real-time data communication between the control center and the vehicle. At the same time, a reengineered DRT system must support all three major types of trip requests: immediate response, standing orders (subscription), and advance reservation. The vehicle-scheduling algorithms must be capable of inserting prebooked trips into vehicle tours that are developed in real time.

To most efficiently use the RF communication channel, information must be transmitted digitally from central site to vehicle and vice versa. This includes dispatching messages sent to the vehicles and data and status information sent back to the central site. Voice communication must also be available. In most cases, the driver's routing decisions should be determined by the computer software; stop sequencing should be under system control. Messages displayed on the terminal in the vehicle should direct the driver to the next location (street level routing can be left to the driver or suggested by the computer).

There should be a simple, efficient, and reliable means of obtaining data about users and their specific trips at the time they access the system (i.e., board the DRT vehicle). A system in which DRT users carry cards containing passenger and fare information is most efficient for this purpose, but this requirement must also be met in systems where passengers do not use cards. This requires communication between the central computer and some type of intelligent in-vehicle device. In addition, the central computer should be able to determine the status of any vehicle or passenger at any time; passengers should be automatically tracked as they move through the system.

Finally, a reengineered DRT system should support any reasonably complex fare structure (e.g., based on zones, straight line mileage, time of day, etc.), a fully automated accounting/billing system allowing multiple funding sources to be billed for different users for different types of trips, and a comprehensive and fully automated data analysis and reporting system. Both data collection and the system of data flows should be fully automated. Participants in the system should not have to write down information or enter data into the computer after the fact; all information should be obtained in real time and stored in computer data bases, either in the vehicle or at the central site.

To summarize, the functional requirements of a fully reengineered DRT system are the following:

- Real-time scheduling and dispatching of trips;
- Ability to handle advance reservation and subscription trips;
- Real-time digital data communication between vehicle and central site;
- Voice radio capability for nonroutine circumstances;
- Computer control of vehicle routing (stop to stop) decisions;
- Computer monitoring of vehicle and driver activities;
- Automated in-vehicle collection of data on passenger trips;
- Automated tracking of passengers in system;
- Automated determination of approximate or exact location of any vehicle in system;
- Automation of all routine data collection and analysis activities;
- Automated fare calculation, billing, and financial accounting capability;
- Automated generation of management and government reports; and
- On-line access by system administrator to continuously updated information on all aspects of system operations.

PROFILE OF A REENGINEERED DRT SYSTEM

On the basis of the preceding functional requirements and the actual availability of hardware and software, it is possible to describe the operation of a reengineered DRT system. The only element of this system that cannot be implemented using off-the-shelf technology is the real-time scheduling/dispatching software. The other components of the system are already operational, often in numerous settings—although not usually DRT systems.

Figure 2 shows an overview of this reengineered DRT system. Not surprisingly, this figure bears a great deal of resemblance to Figure 1, the vision of DRT of 20 years ago. The major differences are the addition of the in-vehicle computers (which had not even been conceived of in 1970) and the downsizing of the computer hardware at the central site. The mapping interfaces to the AVL and vehicle dispatch systems also represent new features compared with the system of 20 years ago. What cannot be seen in the comparison of Figures 1 and 2 is the dramatic improvement in cost-effectiveness and performance of the component technologies over the past 20 years.

Most of the operations in this hypothetical but realistic DRT system are fully automated. A user calls on the telephone to place a trip order, and as soon as the order entry clerk has entered the individual's last name, the computer supplies the passenger record. This includes a list of the five most frequent trips (origin and destination addresses) made by this user. The order entry clerk finds that one of these previous trips is exactly the same as the current trip request and simply moves to that trip and enters it into the system. The computer calculates a fare for this trip. After a wait of a few seconds, during which the computer determines which vehicle to assign this trip to and calculates the new vehicle schedule, the computer informs the order entry clerk that the vehicle will pick up the passenger 35 min from now, with a window of 5 min before and 10 min after the promised pickup time. The order entry clerk informs the passenger of the pickup time window and the fare, and the trip booking transaction is complete.

Behind the scenes, the scheduling/dispatching software generates a dispatch message and sends it over the network to the communications computer. The communications computer transforms this dispatch message into an encoded data packet and delivers the packetized message to the network controller RF modem, which deciphers the message to determine to which vehicle to send it and then transmits the data packet to that vehicle using the RF channel. The modem in the vehicle receives the data packet, checks for errors, and, on determining that the data are correct, returns an acknowledgment to the network controller modem. The communication computer is informed that the message has been successfully delivered to the vehicle.

Back at the vehicle, the modem transmits the data packet to the in-vehicle computer, which decodes the data and then displays the text message on the display terminal. The driver acknowledges acceptance of this trip by pressing a button on the display terminal, and the trip acknowledgment is sent back to the central computer. Software in the in-vehicle computer places this trip request into the proper order of stops, making adjustments to the current stop sequencing if necessary.

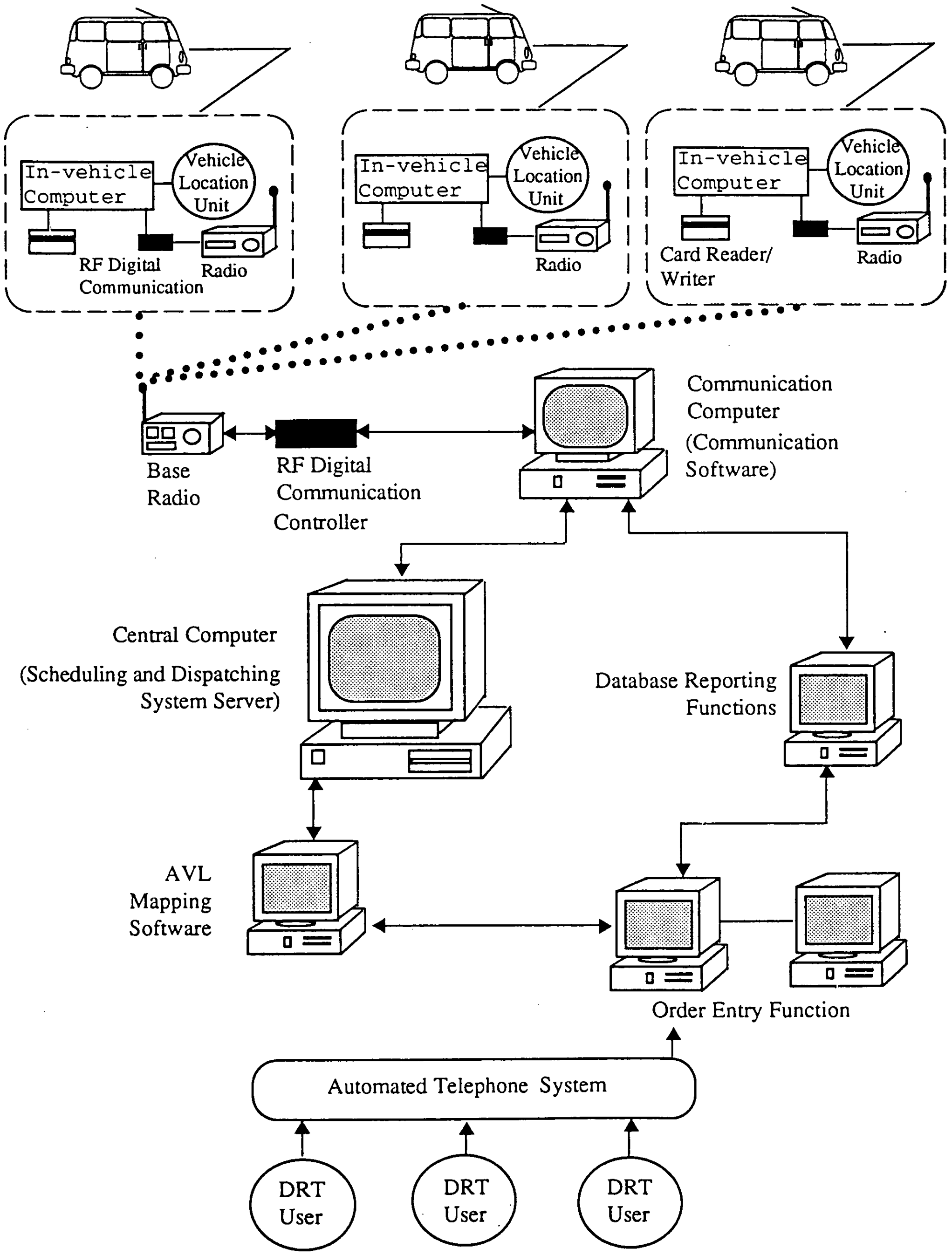

FIGURE 2 Concept of reengineered DRT.

In some cases, the software in the central computer decides to use the AVL system to obtain precise information on the location of the vehicles that are candidates to serve the trip. It requests the communications computer to poll the in-vehicle computers in the vehicles selected as the best candidates for trip assignment. A request is sent to each of these in-vehicle computers to transmit its current location, which is being continuously updated by the GPS receiver unit. Within a few seconds, the locational data are delivered back to the central computer, where the scheduling algorithms use them to assign a vehicle to the trip request.

The in-vehicle computer directs the driver how to proceed along the vehicle tour. At each stop, the display terminal informs the driver where to proceed next; the driver can also scroll through the next two or three stops. As changes are made to the vehicle's schedule, they are eventually reflected in the in-vehicle computer's directions to the driver.

Automation also encompasses passenger processing in the vehicle. On boarding the vehicle, the passenger hands a combination identification/fare payment card to the driver, who inserts it into a card reader/writer where passenger and fare information is extracted. The in-vehicle computer now knows that this passenger is on board and will track the trip. On arriving at the destination, the passenger again hands the card to the driver for insertion into the card reader/writer, the appropriate fare is calculated and deducted from the stored value remaining on the card, and the passenger's trip record is completed. The in-vehicle computer now contains a complete record of the passenger's trip, including boarding and alighting times and odometer readings, the fare paid, and the payment medium. This data record can be sent by the in-vehicle computer back to the central computer as soon as the passenger trip is completed or whenever the system requests it. The in-vehicle computer is also continuously recording information about vehicle operations (speeds, time spent at stops, etc.) and driver activities, which is transmitted to the central computer on request.

During the course of the day, the dispatch supervisor in the DRT control center is able to monitor the status and performance of the system from a computer terminal. The central computer is continually receiving data from the in-vehicle computers about events occuring in the system.

At the end of the day, all of the data generated by the day's operations are loaded into the central computer's data base system from the in-vehicle computers, the scheduling/dispatching system, and the communications computer (many of the data are loaded during the day as transactions occur). Management reports are then generated as well as reports needed by government agencies that finance the DRT system. In addition to uploading data to the central computer, each in-vehicle computer is at this time loaded with a new list of customers who will have their fare cards replenished the next time they access the system. Any changes to system parameters are also downloaded to the in-vehicle computers. The system is ready for the next day's operations.

This is merely an overview of how a reengineered DRT system would operate. Many features of such a system have been ignored in this description, but it indicates the level of automation available for DRT operations.

COST-EFFECTIVENESS OF REENGINEERED DRT

This reengineered DRT system would cost surprisingly little compared with the normal capital costs of a DRT system. The in-vehicle component of this system could be purchased for less than $4,000 per vehicle, the data communications component for $10,000 or less (exclusive of the in-vehicle RF modems), and the central site software probably for $50,000 to $100,000; the latter estimate is the most uncertain due to the current absence of a real-time-oriented scheduling/dispatching software package. If computer-assisted dispatching software were used, the cost of the central site software would almost certainly be less than $50,000.

Reengineering a 20-vehicle DRT system would cost about $130,000 (exclusive of certain smart card system costs). Costs for each vehicle would be $3,100 to $3,600, categorized as follows: in-vehicle computer and software, $1,800; GPS receiver unit, $600; smart card reader, $300; and RF modem, $400 to $900. Other system costs would total $60,000: communications software and hardware, $10,000; data base reporting software, $5,000; AVL software, $10,000; scheduling/dispatching software, $25,000; and computer hardware upgrade, $10,000.

Reengineering a 75-vehicle system would cost somewhat more, assuming a higher price for the fully automated scheduling/dispatching software and the need for more high-performance computer hardware. Assuming that the central site software would cost $50,000 more and that hardware would cost an additional $10,000, the cost for reengineering this system would be $190,000.

The cost of smart cards and smart card processing software is not included in these estimates due to the large variation in cost depending on number of cards issued, features of the cards, and functionality of the smart card system. The additional cost could range from $25,000 for the 20-vehicle system to $150,000 or more for the 75-vehicle system.

To put these costs in perspective, the capital costs for vehicles for the 20-vehicle system would be at least $500,000 (assuming $25,000 per vehicle) and for the 75-vehicle system would be $1,875,000. The computer and electronic components would have a useful service life at least as long as the vehicles, so they can be amortized over the same time period. Thus reengineering adds 26 percent (and 30 percent or more when all smart card system costs are included) to the capital costs of the 20-vehicle system and about 10 percent (and as much as 18 percent with all smart card system costs) to the capital costs of the 75-vehicle system. The benefits from reengineering—in reduced labor costs for data collection and reporting and improved system productivity, to cite the most obvious—would almost certainly outweigh these additional costs over a 5-year period, and probably much sooner.

Seen from another perspective, the amortized cost of reengineering the 20-vehicle system is $0.125 to $0.150 per passenger trip (depending on smart card system costs) using a 5-year life, 8 percent interest rate, 300 service days per year, 10 service hr per day, and 4.5 passengers per vehicle service hour. For the 75-vehicle system, the cost of reengineering is $0.05 to $0.09 per passenger trip. The most productive DRT systems in the United States have passenger trip costs of $3 to $4; more typical costs are $5 to $8 per passenger trip, and some systems have cost levels exceeding $10 per passenger trip.

From this perspective, the cost of reengineering DRT is extraordinarily low, particularly if the result is improved vehicle productivity. If reengineering improved a system's productivity by merely 5 percent, this alone would pay for the additional cost within 1 to 2 years. And this does not include the labor cost savings made possible by automating the entire data collection, analysis, and reporting function. Developments in technology over the past decade have thus made the initial technological vision of DRT a highly cost-effective alternative to a typically configured current system.

ACTUAL DEVELOPMENTS AND FUTURE PROSPECTS

The DRT system outlined above does not exist today. Nonetheless, some actual or planned systems contain several of the features of this system. The Chicago Transit Authority's paratransit system for the disabled, for example, uses smart cards and hand-held computers. Although it is 12 years old, the OCTD DRT system uses in-vehicle data terminals, digital data communication, and real-time scheduling and dispatching software. The Los Angeles County Transportation Commission is moving toward the development of an AVL system for all public transportation vehicles in Los Angeles County, including paratransit, and is considering equipping at least some of the paratransit vehicles in the county with in-vehicle computers or data terminals. Several other large transit agencies are considering equipping their paratransit fleets (or those of their contract operators) with in-vehicle computers or data terminals. In Medford, Oregon, a Federal Transit Administration–funded demonstration encompassing 30 vehicles includes requirements for in-vehicle computers or data terminals, RF-based digital data communications, and a smart card system.

These developments indicate that reengineered DRT is not merely a technological possibility, but also an increasingly attractive option to the government agencies responsible for organizing and funding DRT services. Transit planners are beginning to discover that the technologies for a new generation of DRT systems are both available and affordable and that technologically simplistic DRT is not necessarily more cost-effective than technologically sophisticated DRT. Moreover, vendors are now marketing these technologies specifically to the paratransit industry. And real-time scheduling/dispatching systems are beginning to be seriously discussed again. These are other indicators that a DRT technology shift may be near.

It is ironic that at a time when DRT appears to have finally achieved widespread acceptance as a transit mode, the typical DRT system is quite backwards technologically compared with the initial vision of DRT, a vision stimulated by technological developments that occurred more than 20 years ago. Nonetheless, as the paratransit industry becomes educated about the operational and cost-effectiveness advantages of these technologies, and as the results of actual experiences with them become widely known, it is likely that increasing numbers of DRT systems will find it advantageous to reengineer their operations.

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Publication of this paper sponsored by Committee on Paratransit.

Impact of Nonresponse Bias on Forecasts of Average Passenger Occupancy

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The magnitude of the nonresponse bias on the prospective elements of employee transportation surveys is estimated. The prospective components of the surveys are designed to forecast percent change in average passenger occupancy (APO) levels in response to transportation control measures suggested for use by the federal Clean Air Act Amendments of 1990. The stated commuting behavior of employees at the Matsushita Electric Corporation of America headquarters facility in northern New Jersey is reported. The application of stated preference techniques to the estimation of mode shift is described, the survey techniques used to generate the choice data are identified, the way in which forecasts of APO levels achievable from various transportation control measures such as parking management and rideshare adjustments are made is described, and an estimate of the magnitude and source of the nonresponse bias is made.

There are many situations in which transportation professionals and planners will need to estimate the mode shift potential embodied in transportation demand management policies. The most recent case derives from the passage of the federal Clean Air Act Amendments of 1990 (CAAA). The act implicitly calls for the use of a causal model that can forecast commuter behavior. The model should quantify the degree of mode shift given the introduction of one or more transportation control measures (TCMs) while holding other factors constant. This paper presents a model of the causal process based on random utility theory. Random utility theory applied to the market for discrete commuting choices is used to build the site-specific empirical models. Two approaches to discrete choice analysis exist: revealed preference and stated preference (*1*). Where little or no information on historical patterns of mode choice in relation to the new TCMs exist, the stated preference approach is used.

This paper focuses attention on the survey methods used to estimate compliance with the "demonstrate convincingly" clause found in Section 108(f) of the CAAA. Employee transportation surveys (ETSs) used to meet the CAAA compliance plan requirements will experience varying degrees of nonresponse depending on the care given to their administration. In addition, transportation surveys are known to be sensitive to nonresponse bias. On the basis of their work in Germany, Börg and Meyburg found that nonrespondents to a transportation survey related to mobility issues are more likely to have lower mobility requirements (*2*). This suggests that ETSs designed, for example, to assess the demand for ridesharing will suffer nonresponse bias from employees who feel captive to their current commuting mode or from those who feel antagonistic toward ridesharing. Thus, both the estimate of the current or base level average passenger occupancy (APO) levels and the forecast change in APO can be biased as a function of nonresponse bias. This study focuses on the second consequence of nonresponse to ETSs—that is, the biases caused in the forecasting of APO change.

THEORETICAL MODEL

The choice of commuting mode by an individual employee is modeled as an indirect utility maximization problem (*3*). The individual utility maximizing model is combined with the concept of the representative utility functions to provide the basis for linking individual behavior with aggregate mode choice probabilities. The mathematical process of describing this behavior takes place in two steps. First, the individual utility function is defined; a generalized version of this function is displayed in Equation 1.

$$U_i = \alpha_0 + \alpha_1 W_1 + \ldots + \alpha_n W_n + \varepsilon_i \tag{1}$$

$$U_i = V_i + \varepsilon_i \tag{2}$$

where

U = random utility function,
V = systematic component of the utility function,
W = attributes of each commuting mode (i) for all employees,
α = the set of utility coefficients, and
ε = individual specific deviations between the representative components of utility and Individual q's evaluation of Mode i.

Utility functions of this form are linear in their parameters. The functions can be combined into a relatively simple model describing the probability that Individual q will choose Mode i over another (j) offered by the market. When the error term is assumed to have a Weibull distribution, the logit model for determining the mode selection probabilities is produced. The parameter estimates (α) are derived through a maximum likelihood procedure; this procedure produces scaled coefficients. Whereas several potential solutions are available to quantify the scaling factor, they were beyond the scope of this study (*4*). When only two commuting alternatives are presented to the employee, the choice is modeled as a binomial logit process. The mathematical model is shown in Equation 3.

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$$P_i = \frac{e^{V_i}}{e^{V_i} + e^{V_j}} \qquad (3)$$

P_i represents the probability that individuals with utility functions V_i and V_j will choose Alternative i. Individual deviations from the systematic utility function no longer appear in the logit equation. The individual deviations from the systematic utility generation process are modeled as being identically and independently distributed error terms with a mean of zero and constant variance.

The data used to specify the arguments in Equation 3 are derived from stated choice (SC) experiments. SC, a subset of stated preference analysis, is a relatively new approach to discrete choice analysis (*5*). It is most commonly used in situations where a data base consisting of actual choices among transportation alternatives does not exist (*6*). Essentially, SC presents a decision maker with the choice among alternative modes. Each mode must be carefully described and embedded in a hypothetical choice scenario known as a choice task. The independent variables or attributes are designed to realistically create the transportation choice situation facing the subject. Each subject responding to an SC experiment will examine a number of choice situations. Each choice situation is created by selecting reasonable values for the mode-specific attributes. The attributes are usually designed such that the matrix of attribute values forms an orthogonal space (*7*). Focus groups, simulations, and pilot tests are built into the research design to ensure that the design attributes, the values selected for each attribute, and the structure of the instrument depicting the hypothetical choice situation are understandable and reasonable and that the logit model is capable of recovering estimators of the underlying parameters.

DATA GENERATION PROCESS

Data used to generate SC models are taken from sample surveys. In the case of studies involving compliance plans for the CAAA, a sample of employees working at a given site is taken from the employer. These individuals will receive the ETS instrument.

This paper focuses on research performed at the headquarters facility of the Matsushita Electric Corporation of America (MECA). The firm also has a site in southern California; thus, its management is familiar with the need to plan for the upcoming CAAA compliance process. The choice of the research site was essentially determined by the presence of a cooperative management team. Management did not limit the number of times that researchers could contact employees, nor did management place any barriers on the contents of the survey instrument. On the other hand, management permitted more than three dozen employees to take time during work hours to engage in focus group meetings preliminary to preparing the survey instrument. It was during these sessions that the attributes and their value ranges were established. Comfortable meeting rooms with refreshments were provided for the focus groups. Before the execution of the SC instruments, management permitted the researchers to execute 16 pilot tests in group sessions permitting immediate feedback to the researchers. The research design is described elsewhere (*8*).

Three survey instruments were created for the study; each was designed for a mail-back self-completion form of administration. The first instrument to be distributed to employees was a traditional ETS. It contained questions relating to the current commute to work, attitudes and intentions toward ridesharing, and some socioeconomic information. Table 1 indicates that the questionnaire was sent to 1,948 employees in spring 1991. By the end of that spring, 750 employees had responded with completed and usable instruments. The rate of nonresponse to the ETS was 61.5 percent. Since there was only one response enhancement technique used to increase the number of responses (a thank-you letter), the response rate was well within the range of experience for other ETSs administered in the region. However, a nonresponse rate of over 60 percent leaves much room for bias.

The two other survey instruments were used to measure the magnitude of the nonresponse bias. Each of the second wave survey instruments contained a 16-choice-set SC experiment. The first SC experiment was given to a random sample of 300 employees selected from the respondents to the ETS survey. Given the results of Börg and Meyburg, the mode choice probabilities derived from this sample were hypothesized to be biased toward higher rates of mode shift to ridesharing than will actually occur. To estimate the magnitude of the nonresponse bias, a second SC experiment was given to a random sample of nonrespondents to the original ETS survey. The responses to both instruments are needed to measure the magnitude of nonresponse bias. Table 1 summarizes the response frequencies for the three surveys.

TABLE 1 Response Frequencies for Stated Choice Experiments Held During Fall 1991 and Spring 1992

Category of Employee	Spring 1991 ETS Survey	Fall 1991 SC Experiment	Spring 1992 SC Experiment
Total number of surveys administered	1,948	300	400*
Surveys returned	750	160	145
Surveys completed with compensatory behavior	na	141	107
Surveys completed with non-compensatory behavior	na	19	38
Only SOV chosen	na	14	26
Only Rideshare chosen	na	5	12

na: not applicable.

* The additional 100 instruments over the number administered in the fall were prepared and administered to randomly selected employees from the non respondent sample. However, these instruments did not contain the name of the employee. The hypothesis was that anonymity would encourage an increase in the response rate. Eleven responses were returned from this process and combined with the other instruments returned during the remainder of the spring survey. As a practical matter, the hypothesis was rejected and all remaining instruments were administered with the name of the employee clearly identified on the front page.

ESTIMATION OF NONRESPONSE BIAS IN THE MODE CHOICE MODEL

The logit estimators derived from the first SC survey are hypothesized to be subject to nonresponse bias. The approach used to estimate the magnitude of the bias is based on the analysis of covariance. The analysis pools the responses from the two SC surveys, uses a dummy variable to distinguish between the two samples, and estimates a logit model. The coefficients estimated from the pooled samples can be compared with those derived from the non-ETS respondent subset. The analytical model is shown in Equation 4.

$$V_i = \alpha_0 + \alpha_1 W_{i1} + \ldots + \alpha_m W_{im} + \gamma_0 d + \gamma_1 dW_{i1} + \ldots + \gamma_n dW_{in} + \varepsilon_i \quad (4)$$

where d represents the dummy variable assigned the value of 1 for the nonrespondent sample, and 0 otherwise. The remaining terms are the same as defined for Equation 2.

All of the independent variables are included in the pooled data set; their contribution to the utility of an alternative is represented through the set of parameters $\{\alpha_m\}$. Data obtained from employees responding to the original fall 1991 survey, the sample that may be susceptible to nonresponse bias, are given the opportunity to exhibit a significant difference from the spring 1992 sample through the set of parameters $\{\gamma_0, \gamma_n\}$. When elements of this set of parameters are found to be statistically significant, nonresponse bias is presumed to be present within the original sample.

Microeconomic theory provides the logical support for the inclusion of attributes to a utility function that represent surrogates of price and income terms. However, where other factors representing individual taste determinants of demand or choice are absent, random parameter estimates can be inadvertently produced. The common solution to this problem is the use of a set of socioeconomic characteristics that stabilize the values of the estimators of the mode-specific attributes (*4*).

The set of independent variables is partitioned into the two classes: socioeconomic characteristics and mode-specific attributes (*9*). Socioeconomic variables such as gender, age, employment status, availability of cars, possession of driver's licenses, marriage and family status, and occupation of spouse are used to specify systematic increments to the utility function. This set is augmented with a set of attitudinal and intentional dimensions underlying the employees' choice of commuting mode (*10*). Attitudes toward ridesharing in general are elicited through a dichotomous seven-step variable representing the pleasantness of ridesharing. Similarly, the intention to rideshare, believed by social psychologists to be the precursor to the act of ridesharing, is a dichotomous variable indicating the likelihood of ridesharing in the fall following the study.

Attributes of the commuting modes form a second class of independent variables. Among these variables are policy variables such as parking charges, the existence of preferential parking, flexible work hours, and rideshare incentives including payment mechanisms and guaranteed ride home programs. In specifying incentive programs it was found essential to incorporate realistic constraints on the program reflecting comfort, convenience, security, frequency of service, and so forth, as appropriate. This study has used the time cost of travel as the specified constraint for each ridesharing alternative or attribute.

ESTIMATES OF THE LOGIT PARAMETERS

The model consisting of Equations 3 and 4 was estimated through the use of the binomial logit module contained within the ALOGIT program (*11*). Table 2 gives the logit equation and several goodness of fit statistics. The variables whose coefficients were found to be statistically significant at the 0.05 level are reported along with the utility equation in which they were placed. The pooled component of the model was estimated through the use of 3,664 observations. The observations derived from employees who were nonrespondents to the original ETS numbered 1,646. The spring 1992 sample produced the coefficient estimators found in the nonrespondent section of Table 2.

Goodness of fit of the overall model is judged on the basis of the rho bar squared statistic. The value of 0.24 is well within the range 0.2 to 0.3 considered to be satisfactory (*12*). Seventeen variables fit to the pooled sample's observations produce coefficients that are statistically significant at the 0.05 level. Seven variables taken from the spring 1992 sample were also found to be significantly different from zero. However, because of small changes in the survey instrument between the fall 1991 and spring 1992 administrations, several of these variables cannot be used as clear evidence of nonresponse bias. For example, the week of the year that the survey was administered is a one-time-only seasonal indictor. The spring 1992 values do not represent the identical underlying phenomenon contained within the fall 1991 indicator. Similarly, two variants of a guaranteed ride home program and a business day trip vehicle were added to the attribute space for the spring 1992 survey. However, the remaining socioeconomic variables indicate that nonresponse bias is present.

ANALYSIS OF THE LOGIT MODEL

Table 2 gives the final commuting choice model for MECA employees. The first section of the table indicates the attributes or variables obtained from the pooled sets of samples; the second section indicates the coefficient estimators for the variables obtained from the spring 1992 sample. For the pooled sample, 11 socioeconomic and attitudinal variables were used in the final model. In interpreting the coefficients, the mode-specific utility function in which the variables were placed must be known. The utility generated in the SOV equation is shown to increase for clerical workers as they grow older. However, utility for the rideshare option shifts upward when the employee's spouse is a homemaker. Finally, the season during which the employee completes the survey also affects the choice. As the week of the survey enters the fall and moves toward winter, there is a slight but statistically significant increase in the utility for the SOV option. This process unwinds during the spring.

The attitudinal and intentional indicators for the pooled samples are shown to be important and significant determi-

TABLE 2 Binomial Logit Equation for Commuting Choice Decisions Made by Employees of MECA, Fall 1991 and Spring 1992

Attribute	Mode* Specific Utility Equation	Logit Coefficients
Pooled Samples		
Socioeconomic Attributes		
Age of Clerical Employees	SOV	0.016 (5.0)
Household size of female Employees	RS	0.051 (1.5)
Week of survey for fall survey	SOV	0.039 (8.4)
Employee's spouse is a homemaker	RS	0.29 (2.5)
Intention to Rideshare		
Slightly likely	SOV	-0.48 (2.5)
Quite unlikely	SOV	0.56 (4.7)
Extremely unlikely	SOV	0.86 (8.3)
Attitude toward Ridesharing		
Extremely unpleasant	RS	-0.27 (1.6)
Quite unpleasant	RS	-0.45 (3.1)
Slightly unpleasant	RS	-0.22 (1.9)
Quite Pleasant	RS	0.37 (2.8)
Commuting Attributes		
Parking Charge	SOV	-0.81 (13.1)
Parking Charge Squared	SOV	0.047 (5.7)
Extra time lost	RS	-0.041 (12.1)
Rideshare subsidy	RS	0.29 (4.4)

Attribute	Mode* Specific Utility Equation	Logit Coefficients
Non Respondents to Employee Transportation Survey		
Rideshare subside squared	RS	-0.018 (1.7)
Guaranteed Ride Home (unconstrained response)	RS	1.32 (12.0)
Socioeconomic Attributes		
Household Size of female employees	RS	-0.33 (6.1)
Cars per household	SOV	0.29 (3.4)
Week of survey for spring survey	SOV	-0.025 (5.1)
Commuting Attributes		
Parking Charge	SOV	0.058 (1.4)
Guaranteed Ride Home 25 minute wait time	RS	0.99 (1.8)
Guaranteed Ride Home 55 minute wait time	RS	0.39 (2.4)
Business day trip vehicle	RS	0.49 (2.7)
Initial Likelihood		-2539
Final Likelihood		-1922
Rho bar squared		0.24
Number of Observations (pooled samples)		3664
ETS respondents (fall 1991 sample)		2018
ETS non respondents (spring 1992 sample)		1646

*SOV: single occupant vehicle commuting option, RS: rideshare commuting option.

nants of mode choice. As the attitude regarding ridesharing increases from quite unpleasant to quite pleasant, the utility exhibited in choice behavior toward the ridesharing option increases significantly. Similarly, when the elicited intention toward ridesharing at a future time becomes increasingly unlikely, the incremental utility exhibited for the SOV option increases strongly.

The TCMs evaluated by the employees included flexible starting time, preferential parking, parking charges, guaranteed ride home, business day trip vehicle, and the rideshare adjustment. Preferential parking was not found to produce significant coefficients for any of the logit models; the flexible starting time under certain specifications of the model would generate significant positive coefficients linked to the single occupant vehicle alternative. However, in the final model the coefficients, though positive, were not significant at the 0.05 level and therefore were omitted from the table.

The imposition of a parking charge significantly reduces the utility found in the drive-alone option. The quadratic form of parking change is reported in the final equation. For the range of parking charges ($0.00 to $7.00 per day), the coefficients show a diminishing marginal disutility for each dollar increase in parking fees.

The rideshare equation for the pooled samples was specified with three attributes: time lost picking up the rideshare partner, the value of the rideshare subsidy expressed in a quadratic form, and the existence of an unconstrained guaranteed ride home program. Time lost while picking up the rideshare partner produces a strong disutility for the rideshare option across all employees. The rideshare adjustment, expressed in the form of a coupon representing cash for a daily lunch at the cafeteria, produces a positive but diminishing rideshare utility. Over the range of values studied in the experiments ($0.00 to $3.50), the results indicate a diminishing marginal utility with increasing value of the rideshare coupon.

The nonrespondent sample (spring 1992 sample) produced three socioeconomic variables that were significantly different from the pooled sample. The household size of female employees is a significant factor influencing the use of the SOV option by nonrespondents to the ETS survey. Similarly, as the number of cars per household increases, their role in increasing the probability that the respondent uses the SOV increases.

The role of the nonresponse phenomenon in affecting the performance of the TCM is shown in the section of Table 2 labeled Commuting Attributes. None of the TCM that were found significant in the pooled model had significantly different coefficients in the nonrespondent sample's model.

The guaranteed ride home program was presented to employees in several forms. In the fall 1991 survey, the program was described as free of charge to employees needing it; no effort was made to specify its performance attributes. Early analysis of the results indicated that the respondents viewed this type of program as a relatively even substitute for their personal automobile. Since this is not the case in practice, it is hypothesized that the coefficient was affected with unconstrained response bias. Adjustments were made in the spring 1992 survey. Performance constraints were placed on the guaranteed ride home program; these characteristics specified the time, type of vehicle used, payment for vehicle services, and reimbursement procedures. The program was specified as one in which the employee had to obtain permission from a supervisor to trigger the reimbursement provisions of the program, then the employee had to call an approved cab company and wait a specified number of minutes for the vehicle to arrive at the site. The time parameters were set at 25- and 55-min waits.

The logit model shows that the unconstrained guaranteed ride home coefficient has a strongly positive impact on the utility associated with the rideshare option. The guaranteed ride home programs constrained by time, comfort, and convenience characteristics have smaller marginal utility coefficients than the unconstrained version of the program. When the appropriate elements of the variance covariance matrix of the estimators are incorporated in the difference of the estimators analysis, each coefficient is statistically different from the other at the 0.05 level of significance.

The final TCM studied in the analysis is the business day trip vehicle. The business day trip vehicle is constrained to be one for which approval of a supervisor is required and a 10- to 15-min wait time would be needed to bring the car to a convenient location. The presence of the business day vehicle program produces a strong and statistically significant increase in utility derived by the rideshare option.

DERIVATION OF THE APO LEVEL FOR THE MAJOR EMPLOYER

The performance indicator used to measure compliance with the CAAA's employer trip reduction provisions is the APO level. Essentially, a site's APO is its employment level divided by the number of vehicles used to bring employees to the site. Compliance with the 1996 goals of the act will require the site to meet the region's target APO. For the average site, the goal will be approximately 25 percent greater than the baseline or current APO.

The baseline APO for the MECA site is taken from the ETS. The forecast change in APO caused by the new TCM is taken from the logit equation. The probability that a class of individuals will choose a commuting alternative depends on their membership in one or the other sample, their socioeconomic characteristics, and the values of the TCM attributes incorporated in the model. This can be seen in several ways. First, the estimated parameters of the logit model show that there are slight differences in the marginal utilities of the mode-specific attributes. Second, the socioeconomic characteristics of the members of the samples are significantly different. Third, the weighting factors through which the total employment APO value is calculated differ across the samples.

In the case of a single sample, such as that obtained in fall 1991, a one to one weighting practice can be used to calculate the site's APO. Equation 5 shows the probability that employees will choose to drive alone to work conditioned on their socioeconomic characteristics and the specific values placed on each of the design attributes.

$$\overline{P}_s = \sum_{q=1}^{Q} P_{s,q}/Q \qquad (5)$$

where Q is the number of employees in a sample and P is the probability of driving alone to work. When $s = 1$, individual probabilities are aggregated within the sample of employees who were respondents to the original ETS (the fall survey); when $s = 2$, individual probabilities are aggregated within the sample of employees who were nonrespondents to the original ETS (the spring survey); and when $s = T$, the individual probabilities are aggregated within the pooled samples of employees.

Equation 5 forms the basis for the calculation of the firm's APO under the assumption that the sample of employees on which it is based is representative of the total employment at the site. However, Equation 5 does not account for the nonresponse bias present within the membership of the 1991 sample. Assuming that the spring 1992 sample accurately represents the employees who were nonrespondents to the original ETS survey, an estimate of the employment site's mode choice probability can be derived. This is done by combining the mode choice probabilities derived directly from the logit model with the sampling rates for both samples. Equation 6 shows that the probability of choosing a given mode is the weighted average aggregate mode-specific probability for the two samples.

$$\overline{P}_T = \frac{f_1}{f_T} \cdot \overline{P}_{s=1} + \frac{f_2}{f_T} \cdot \overline{P}_{s=2} \qquad (6)$$

where f represents the number of individuals in each sample.

The site-specific probability of driving alone to work must be linked to the policy indicator reflected in the Clean Air Act. To do this, APO is operationally defined in terms of available data to be the number of employees reporting to work at a given site divided by the number of vehicles that bring them to the site. Equation 7 shows the procedure for calculating the value for APO.

$$\mathrm{APO}_s = \frac{n_s}{(n_s \cdot \overline{P}_s) + [n_s \cdot (1 - \overline{P}_s)]/K} \qquad (7)$$

where n_s is the size of the sampling frame for Sample s and K is the average number of persons in multioccupant vehicles currently using the firm's parking facility.

Official baseline AVO values have not yet been certified for New Jersey. Therefore, for the purposes of this study, the baseline AVO is set at the value of APO_s appropriate to samples. For the AVO calculation, all mode-specific attributes other than the extra time for ridesharing were set at zero. The rideshare time was set at 15 min. The APO value derived from these attribute values and estimated from the fall stated choice data base is 1.08 employees per vehicle. The ETS administered in spring 1991, describing actual behavior, produces an estimate of the baseline APO of 1.07. This suggests that the scaling factor is probably close to 1.0 and will not significantly bias the conclusions taken from the study. The baseline APO reported by the members of the spring 1992 survey (the nonrespondents to the original ETS) is 1.15. Whereas we do not explore the consequences of the nonrespondent sample's APO versus the respondent sample APO, there appears to be nonrespondent bias in the estimation of the baseline value.

The forecast values of APO are derived by assigning specific values to the design variables: parking charge and rideshare adjustment. For example, when a $1.00 parking fee is placed in Equation 4, a new value for APO_s is generated. The percentage change between the forecast value and the baseline value is taken as an estimate of the impact of the parking fee change in mode shift behavior.

The estimated utility coefficients given in Table 2 indicate that nonresponse bias is present in the original ETS survey and that it is due to the different socioeconomic characteristics of respondents in the fall as opposed to the spring survey. Had a value for the percent change in APO been based on the logit model restricted to the original ETS sample, bias would be present. The magnitude and direction of the bias can be estimated by first forecasting a series of APO values based on the fall 1991 sample. Essentially this means using Equations 5 and 7 with the value of Subscript s equaling 1. A corresponding series estimating the true APO for the firm can be derived by using Equations 6 and 7 with the value of s indexed to T. Given that the baseline AVO is the same for each series, the percent change in APO conditioned on TCM policy and survey sample procedures can be derived. A partial series of these values is given in Table 3.

The first column of Table 3 gives a series of design values for parking changes; the values range from $0.00 to $3.25. The second column represents a series of rideshare adjustment values, which in the case of the Matsushita survey instrument represented payment toward a lunch at the corporate cafeteria. The difference between the third and fourth columns represents the estimated level of error associated with nonresponse bias. In general, nonresponse bias produces erroneously high values for the APO. Adjustment of the nonresponse bias by assuming that all nonrespondents are SOV drivers would clearly result in a bias in the negative direction. This can be seen by examining Equation 6 and inserting the value $\overline{P}_{s=2} = 1$ and recalculating Equation 7.

The forecast percent change in APO given either a parking charge or a rideshare adjustment is positive, as theory suggests. However, nonresponse bias appears to be a major factor. When the compliance plans are based on a sample having nonresponse bias, the change is APO is overestimated. For example, Line 4 of Table 3 indicates that an analysis based on a sample having nonresponse bias predicts that a $2.30 parking charge will increase the APO by the necessary 25 percent. In contrast, when nonresponse bias is addressed using samples from both fractions of the site's employee roll, the estimated true percent change in APO is only 19.2 per-

TABLE 3 Percent Change in APO Levels Conditioned by TCMs: Parking Charge and Rideshare Adjustments Given the Presence of Nonresponse Bias

TCM* Policy		Percent change in APO	
Parking Charge	Rideshare Adjustment	Based on sample having non-response bias	Adjusted for non response bias
$0.00	$0.00	Baseline AVO	
$1.00	0.00	8.0%	6.2%
2.00	0.00	19.2	14.3
2.30	0.00	25.1	19.2
3.00	0.00	31.9	23.1
3.25	0.00	35.1	25.3
0.00	$1.00	2.2%	2.0%
0.00	2.00	4.5	4.0
0.00	3.00	6.8	4.5
0.00	4.00	8.9	8.0
$2.00	$1.00	25.0%	18.8%
2.50	$1.25	33.2	25.1

Source: Matsushita Electric Corporation of America, Commuting Management Study, 1992.

*The rideshare commuting option requires employment of a transportation coordinator to aid in the formation of car and van pools.

*Parking charges and rideshare adjustment values are expressed in dollars per day.

cent. Looking further down the table, the appropriate parking charge needed to generate the necessary change in APO is $3.25.

The table also indicates that the rideshare adjustment as described to the Matsushita employees is insufficient in value to generate the necessary change in APO. When the rideshare adjustment is defined as a $4.00 daily coupon for lunch at the corporate cafeteria, the APO adjusted for nonresponse bias increases by 8 percent. This value must not be interpreted as the forecast performance efficiency of the recently enacted $60 Qualified Transportation Fringe for commuter highway vehicles [National Energy Policy Act (P.L. 102-486)]. The product being offered to the employee is different. One is the proverbial free lunch; the other is a free ride. The transit or rideshare subsidy dedicates the entire value of the incentive program to the commuting policy; the subsidized lunch acts indirectly on the rideshare utility function through the utility derived from the MECA cafeteria's lunch and luncheon ambiance. Given no change in the quality of the luncheon experience, the transit/ridesharing subsidy will be more effective in changing APO than the lunch subsidy. However, where the luncheon experience at the site has less utility than an off-site location traveled to by the employee's car, a change in the luncheon experience can increase the site's APO. Ultimately, to estimate the impact of the $60.00 per month transit/vanpool subsidy, the new subsidy program must be explicitly incorporated into a new SC study.

Once nonresponse bias is corrected, the set of programs needed to meet the required 25 percent increase in APO can be derived. In this case a mix of the two TCMs, a $2.50 parking change combined with a $1.25 rideshare adjustment, appears sufficient to meet the site's 1996 goal. Where other TCMs, such as a high-quality guaranteed ride home, were added to the compliance plan, the magnitude of the parking charge could be lowered while still meeting the required 25 percent threshold. Clearly, by combining TCMs into the compliance plan, individual choice is retained. Employees who need to drive alone can do so at a price; those who accept the shift from driving alone to some form of rideshare or transit can be rewarded for the inconvenience they may suffer.

SUMMARY

Major employers in areas found in noncompliance with air pollution regulations will be required to reduce the use of the single-occupant vehicle for commuting purposes. The employers will be required to submit compliance plans showing the policies they will enact to meet trip reduction objectives. ETSs will form the basis for the design of appropriate and effective transportation demand management policies. This work shows that the design and administration of the survey must account for nonresponse bias.

The evidence derived from this study shows that employees who respond to the initial ETS are more likely to be open to new ridesharing alternatives than are the nonrespondent employees. The parking charge erroneously forecast to meet the Clean Air goal is $2.30 per day. After correcting for nonresponse bias, the parking charge rose to $3.25 per day. This finding suggests that response-enhancing survey administration techniques must be used. Alternatively, as was done in this study, a separately prepared sample survey for nonrespondents could be used to adjust the projection model to account for the nonresponse bias derived from the original ETS.

ACKNOWLEDGMENT

The authors wish to thank Anthony Scardino, Jr., of the Hackensack Meadowlands Development Commission, F. Jack Pluckhan of the Matsushita Electric Corporation of America, and the MECA employees for their warm cooperation throughout the study. They thank Arnim H. Meyburg for his generous support and Joel Weiner, Terry Dunn, and the staff of the North Jersey Transportation Coordinating Council for their efforts in stimulating regional interest in the study.

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Publication of this paper sponsored by Committee on Ridesharing.

What Has Happened to Carpooling: Trends in North Carolina, 1980 to 1990

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County-level trends in mode to work, particularly carpooling, for all of North Carolina's counties from 1980 to 1990 are explored. Using 1990 census information, statistics are computed on the extent and relative levels of carpooling. These data are related to changes in demographics, geography, and accessibility. It was found that as a share of work travel, and in absolute numbers, carpooling has declined precipitously in the vast majority of North Carolina's 100 counties in the last 10 years. Overall, carpooling dropped by 122,608 workers—more than 32 percent—whereas total commuting increased 24.4 percent. Of all the counties, only one registered a slight increase in carpooling during the decade. Carpooling was found to be highest—more than 25 percent—in counties that are rural and isolated but within long-distance commutes of major metropolitan areas, including areas outside of the state. Carpooling was found to be lowest in major metropolitan counties and their immediate surrounding suburban counties. Per capita income levels and average travel time were found to be the highest correlates of carpooling: carpooling was found to have declined most rapidly in first-tier suburban counties that have increased greatly in accessibility and in per capita income in the last decade. Declines in carpooling have shown up as single-occupant automobile drivers rather than in public transit or other modes. It is concluded that present programs to encourage carpooling are misdirected, focusing on urban and suburban markets where carpooling is relatively low and ignoring longer-distance rural isolated markets where carpooling is much higher. A restructuring of carpooling programs to better fit the underlying needs of carpoolers, which are driven not by commuting costs but by long-distance job economics, is recommended.

It should come as no surprise to the casual observer of transportation and travel patterns in the United States that automobile travel is increasing and overall average occupancy is declining. Between 1980 and 1990, travel in the United States increased from 1.527 trillion vehicle miles to 2.148 trillion vehicle miles, or about 40.7 percent. This compares with a 9.7 percent increase in population, a 14.4 percent increase in households, and a 17.4 percent increase in vehicles. The preliminary tabulations of the 1990 National Personal Transportation Study (*1*) show that overall automobile occupancies have declined from approximately 1.9 to 1.6 in 13 years. During the 1980s, many states and local governments established urban area carpool programs to encourage commuters to use carpooling for work travel. A considerable amount of federal and state funding, perhaps $150 million in urban areas, has been spent in the last decade to establish these programs and encourage them. As we cross the threshold of the decade, it is useful to review facts about carpooling trends. It is the purpose of this paper to identify and review detailed county-level trends in carpooling in North Carolina, to determine the probable effect of comparable programs on these trends, and to suggest further actions, if any, that might be appropriate to increase the incidence of carpooling and make better use of vehicle availability.

LITERATURE REVIEW

Carpooling was (until recently) a significant share of travel, generally between 17 and 22 percent of most metropolitan work trips. The 1980 census, for instance, showed that most metropolitan areas had about 3 times as much carpooling as transit usage. Most of this carpooling, of course, is privately generated, in the sense that it is not related to local matching programs. U.S. carpooling percentages have been in the 20 percent range since the 1960s. The 1980 census (*2*) reports about 22.4 percent of commuters in 2+ person carpools for the top 34 U.S. cities. Pisarski (*3*) put carpool use at 19.7 percent of commuters nationwide in 1980; the "all metro" number was 19.0 percent, implying that rural carpooling was higher than 20 percent. Using the 1990 National Personal Transportation Study, Hu and Young (*1*) reported an average house-to-work vehicle occupancy of 1.1, implying a carpool rate of 20 percent (employed residents minus jobs). This implies a carpool market of about 22 million. However, Pisarski's review (unpublished data, 1992) put the total at 15.39 million, about 13.4 percent of commuters.

Organized carpool programs, now common in major cities, have not been particularly successful. Ferguson (*4*) and Oppenheim (*5*) note that most such programs produce much less than a 1 percent reduction in regional vehicle miles traveled (VMT). Hartgen and Brunso (*6*) compared employer-end and residence-end carpool matching and found them to be equally effective, but insignificant overall in producing area VMT reductions. In reviews of carpooling "behavioral sensitivity," Pratt (*7*) and Dupree and Pratt (*8*) report that the effect of park-and-ride lots will be modest but observable: typically about 20 to 30 cars per "fringe" lot but upwards of 1,000 cars for close-in "peripheral" lots served by buses.

More successful, but also narrowly targeted, are employee-sponsored services including vanpools. Wegman (*9*) reports average carpool use of 16.7 percent and B/C rates of 2.2 to 21.2 in a review of 160 employer-sponsored services nationwide. Ferguson (*4*) also found substantially more effective performance when the organization is committed to the program, and Beraldo (*10*) reports an average of a 23 percent "placement rate" for inquiring employees within employer-sponsored programs. Spence (*11*) reports growing interest in

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these services nationally, more than 586 nationwide, often called transportation management associations. Southern California's Regulation XV has also resulted in small, but statistically significant, increases in the average vehicle ratio (employees per vehicle) from 1.21 to 1.25, about 2.7 percent (*12*).

High-occupancy vehicle lanes (HOVs) that are open to carpoolers, as most are, can show substantial use within the service corridor. Fuhs (*13*) reports growth in HOV lanes from 15 mi nationwide in 1970 to 300 mi in 1989, across 20 cities. Turnbull and Hanks (*14*) report 332 mi nationwide in 1990; in lanes with full data available, they report that 19.6 percent of commuters are in carpools. The cost of these systems has been about $1.5 billion so far; if planned facilities are built, the total will be 800 mi costing an additional $3.0 billion by 2000.

In a recent review, Wegman (*9*) evaluated the incidence and extent of employer-sponsored carpool programs in U.S. cities and found that a significant number of cities around the country had established employer-sponsored carpool matching services. In North Carolina, for instance, at least 138 lots are now operated by carpool agencies in the four largest metropolitan regions. Not counting additional informal unpaved lots in surrounding counties, approximately 6,800 spaces are available for carpool users. According to the latest estimates (Table 1), more than 13,112 individuals are registered with carpool matching services in North Carolina's largest cities.

Despite these very considerable government efforts, surprisingly few comparative studies have been done to determine the overall effectiveness of carpool programs on reduction in VMT or related statistics. Most programs do not keep track of breakups in carpools and therefore have no handle on the overall effectiveness of the programs. In one study (*6*), statistical analysis of carpool data against background statistics showed that the effects were far less than originally believed. The overall cost of forming a carpool was found to be between 14 and 21 hr of effort per carpooler attracted.

Carpooling now seems to be dropping rapidly. In preliminary reviews of 1990 census data, Pisarski (unpublished data, 1992) notes radical across-the-board drops in carpooling in virtually all U.S. cities. Nationwide, carpooling fell 32 percent, from 19.09 million to 15.4 million, in just 10 years. Not only have the shares dropped, but absolute numbers have dropped as well. Pisarski notes that other modes (walk, bus) have also declined.

METHOD

The method used in this study is a straightforward comparison of 1980 and 1990 county-level mode-to-work statistics for the state of North Carolina. National data for all states, as reported by Pisarski (unpublished data, 1992) suggest that the trends observed in North Carolina are also occurring nationwide. The methodology is as follows:

1. Overview of aggregate trends for North Carolina's mode-to-work statistics and automobile ownership data;
2. County-by-county comparison of changes in carpooling, automobile ownership, solo occupant commuting, and transit usage;
3. Analysis of correlations between carpooling and changes in carpooling and other behavioral and economic statistics at the county level; and
4. Analysis of the magnitude of organized carpooling using public agency information for major North Carolina cities.

Very little modeling or analytical structure-seeking work is undertaken in this study. The intention is to identify major

TABLE 1 Park/Ride Lots and Vanpool Figures: North Carolina Urbanized Areas

City	# park/ride lots	vanpools	carpooling database	Estimated* lot spaces	Estimated daily use of all lots	Estimated vanpool use
Charlotte (Mecklenburg Co.)	34 in county 12 not served by CHLT transit City owns 2 lots=171 spaces 38% utilized	16 15-seater vans	4500 names	1,700	646	240
Raleigh (Wake Co.)	10 lots 2 in Cary 2-3% utilized	18 15-seaters 4 7-seater 100% utilized	6000 names	600	NA	298
Greensboro (Guilford Co.)	40 in Co. church lots, etc.	14 15-seaters 7 7-8-seaters	NA	2,000	NA	266
Winston-Salem (Forsyth Co.)	approx. 50 lots	31 15-seaters	2612 names	2,500	NA	465
Total	134		13,112	6,800	NA	1,269

*To average 50 spaces/lot

directions of trends and to suggest underlying causes, not to quantify the specific magnitude of relationships; that is left for a later time.

FINDINGS

The following describes the primary findings of our review. Data and supporting materials are shown in the accompanying tables, maps, and figures. Figure 1 shows the overall pattern of the state's major cities and Interstate road system.

Trends by Mode

In the aggregate, commuting travel behavior in North Carolina has changed radically in the last decade. These changes are related to changes in family activities, automobile ownership, economics, and accessibility.

Household automobile ownership has also increased in North Carolina in the last decade (Table 2). In 1980 there were 2.043 million households in North Carolina, of which 219,000 or about 10.8 percent owned no cars. By 1990 the number of households had grown to 2.517 million, whereas the per-

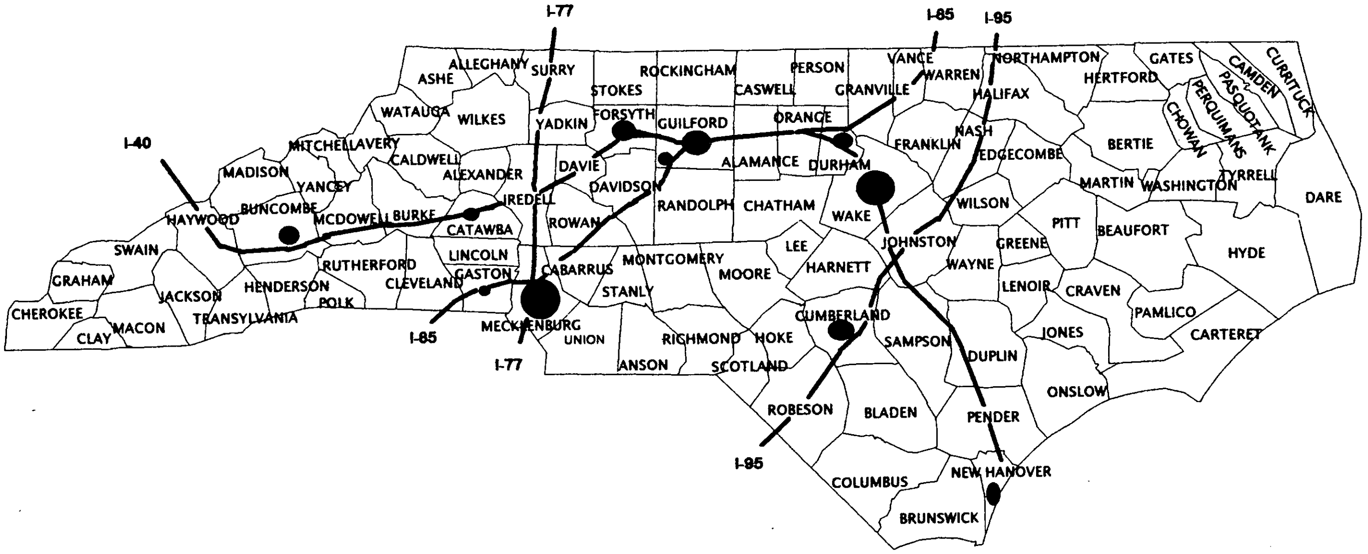

FIGURE 1 North Carolina counties, largest cities, and Interstates.

TABLE 2 Travel-Related Statistical Trends in North Carolina

	1980	(%)	1990	(%)	Percent Change	USA % Change
Total daily person trips	12,938,000		15,246,000		+17.8	
Population	5,881,166		6,628,637		+12.7	+9.7
Workers 16+	2,652,593		3,300,481		+24.4	+19.1
Drove alone	1,756,417	66.2	2,528,168	76.6	+43.9	+35.4
Carpool	653,985	24.7	531,377	16.1	-18.7	-19.3
Public transit	40,100	1.5	33,005	1.0	-17.7	-1.9
Other modes	34,468	1.3	39,606	1.2	+14.9	-5.6
Walk/home work	167,623	6.3	168,325	5.1	+ 4.1	+4.4
Mean travel time, min.	19.1		19.8		+ 3.7	+3.2
Household auto ownership						
TOTAL	2,043,291		2,517,026			
0	219,700	10.8	241,711	9.6	+10.0	+2.0
1	657,989	32.2	786,080	31.2	+19.5	+8.7
2	745,112	36.5	959,128	38.1	+28.7	+25.6
3+	420,490	20.6	530,107	21.1	+26.1	+13.2
HH owned total vehicles	3,409,683		4,294,657		+26.0	+17.4
Vehicles/household	1.67		1.71		+2.3	+3.1
Total vehicles registered	3,871,840		4,919,592		+27.1	

centage of households owning no cars had fallen to 9.6 percent. In 1990 over twice as many households (530,107, or 21.2 percent) owned three or more vehicles as owned no vehicles. Vehicle ownership is not uniform across North Carolina but rather varies substantially by income. Generally, counties with the highest income levels also have the highest rates of car ownership.

The number of workers commuting in North Carolina increased about 24.4 percent in the last decade, compared with an increase in the population of about 12.7 percent (Table 2). The increase has been in the "drove alone" category, which increased from 66.2 percent of commuters in 1980 to 76.6 percent of commuters in 1990. In fact, the increase in drive-alone commuting (771,751) is much greater than the reduction in other modes (123,868). Of the total change, 13.8 percent comes out of other modes, and 76.2 percent was directly solo driver. Perhaps surprisingly, the percentage of workers in carpools dropped 18.7 percent, from 24.7 percent to 16.1 percent of commuters. In absolute terms, carpooling dropped by 122,608. Public transit also dropped by about 17.7 percent, from 1.5 percent to 1.0 percent (7,095 in absolute terms). The percentage who walked to work or worked at home has also dropped relatively. Thus, the most dramatic changes in commuting patterns are reductions in carpooling, coupled with substantial increases in solo driving.

Solo driving commuting is not generally thought of as closely associated with large metropolitan areas; it is often believed that such areas have a higher percentage of carpooling and public transit use than rural, more isolated areas. In fact, just the opposite is the case in North Carolina. Figure 2 shows that solo driving commuting is highest in North Carolina's larger metropolitan areas. Wilmington, Charlotte, Raleigh, Asheville, and Greensboro have high drive-alone rates. These areas also have generally higher-than-average income levels, which are translated into generally higher levels of automobile ownership. On the other hand, changes in commuting alone (Figure 3) have been most rapid in suburban and rural counties, often adjacent to larger metropolitan counties. A few

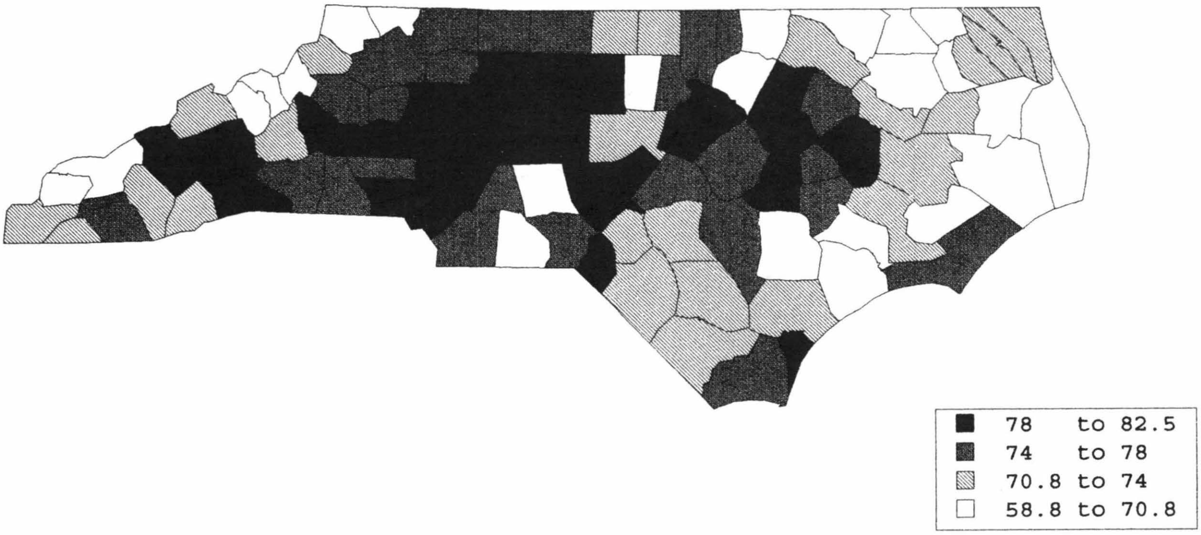

FIGURE 2 Percentage commuting alone, North Carolina counties, 1990 (source: U.S. census).

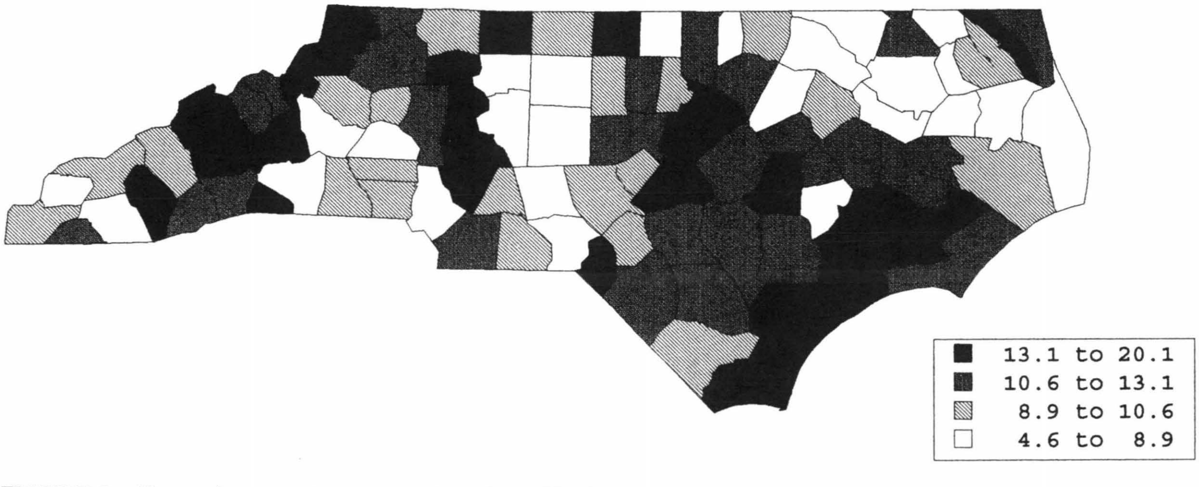

FIGURE 3 Change in percentage commuting alone, North Carolina counties, 1980 to 1990 (source: U.S. census).

counties show both high present solo driver rates and also a very substantial increase in percentage commuting alone; these are counties that have rapidly changed from more rural economies to integrated urban economies in the last decade.

Carpooling is often associated with metropolitan commutes from suburban counties, but in fact carpooling is greatest in North Carolina in rural counties (Figure 4), which have generally lower incomes. It is more accurately associated with the inability to purchase vehicles than it is with long travel times or travel distances. Although the overall percentage of carpoolers has dropped from 24.7 to 16.1 percent between 1980 and 1990, at least 75 of North Carolina's 100 counties have carpool rates greater than 16.1 percent. Two of North Carolina's counties have incidences of carpooling higher than 34 percent. Compared with overall national averages of about 13.4 percent, these are extremely high rates indeed.

Only one county showed an increase in carpooling during the last decade, from 32.3 to 34.5 percent (Figure 5). The decline in carpooling (122,608) has been over 31 times greater than the total use of publicly sponsored carpool or vanpool services.

Public transit commuting has also generally declined, from 1.5 to about 1.0 percent of commuters between 1980 and 1990 (Figure 6). In North Carolina, only the counties containing

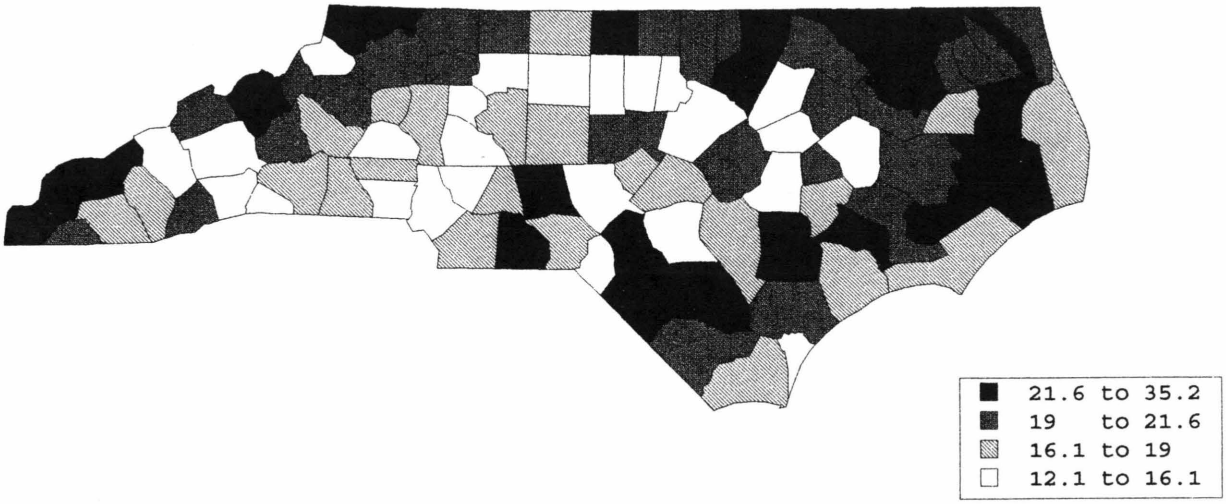

FIGURE 4 Percentage carpooling, North Carolina counties, 1990 (source: U.S. census).

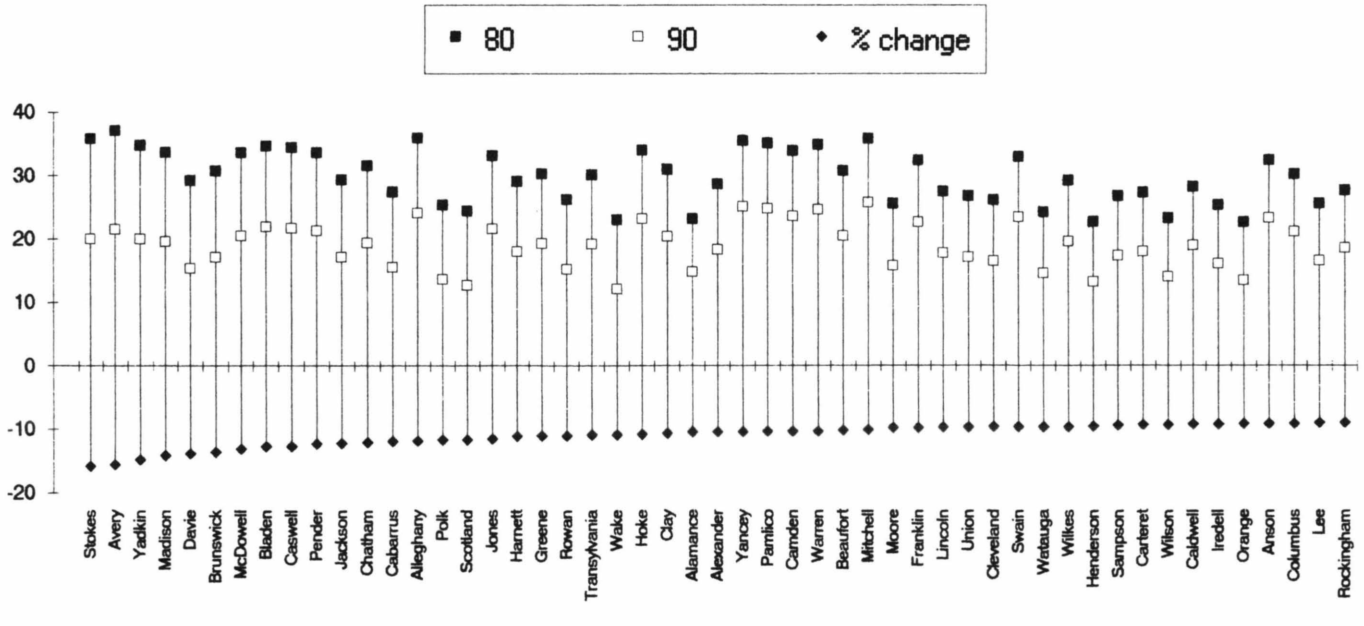

FIGURE 5 Change in percentage carpooling, 1980 to 1990. (*continued on next page*)

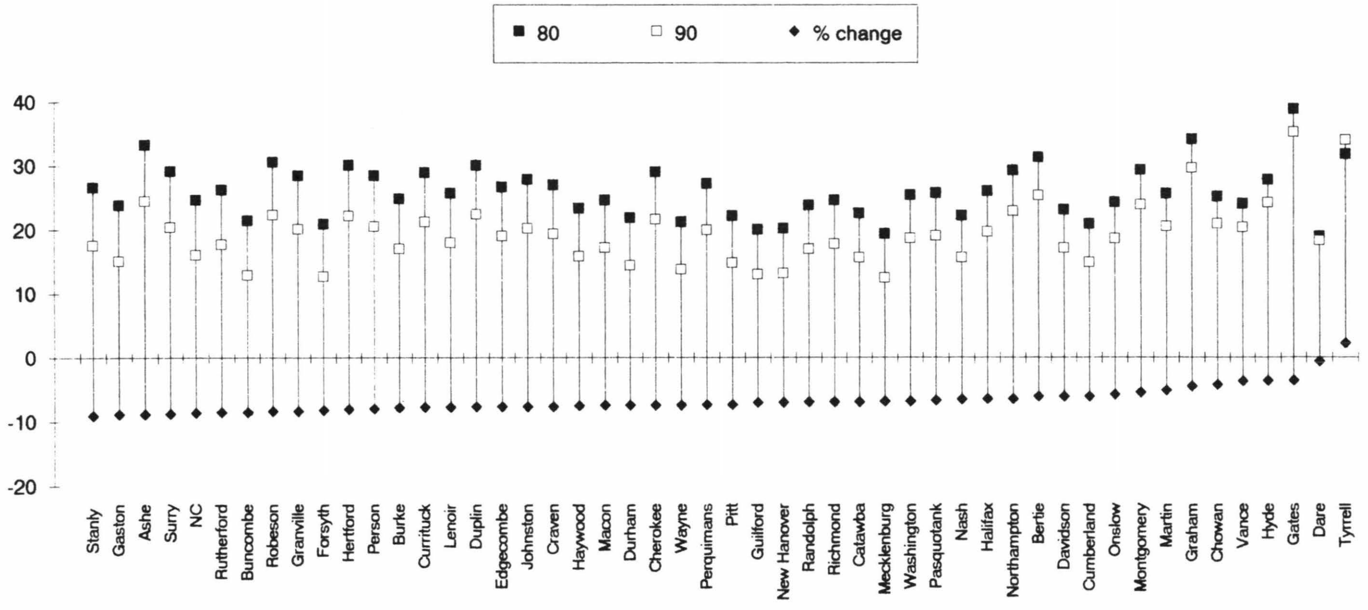

FIGURE 5 *(continued)*

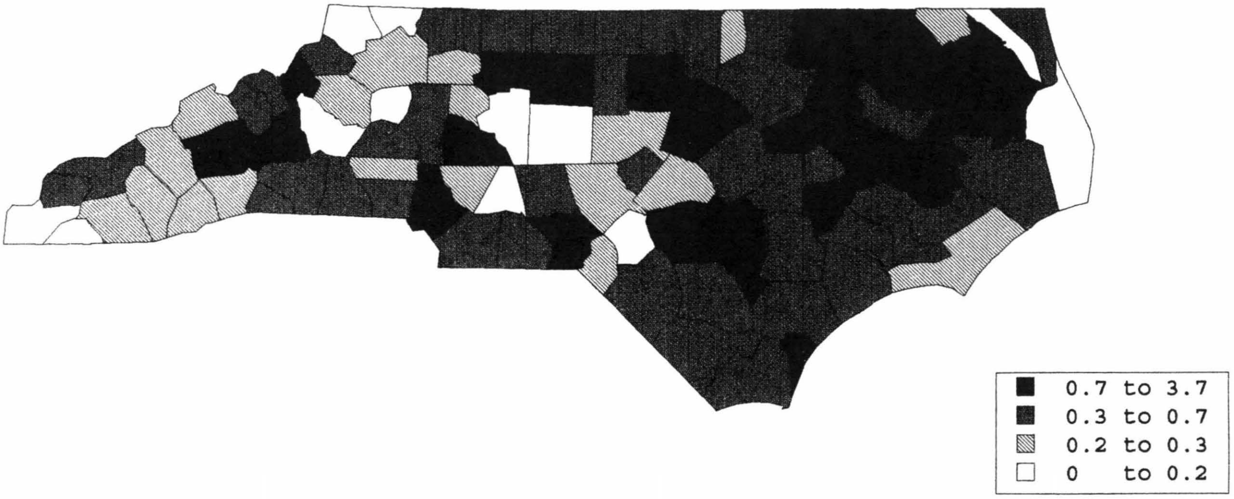

FIGURE 6 Percentage using public transportation, North Carolina counties, 1990 (source: U.S. census).

the four largest cities show transit use greater than 2 percent for commuting.

However, a number of other counties show between 1 and 2 percent transit use, and in no sense can all of these counties be considered urban in character. Whereas several counties have shown increases in transit use in the last decade, the trend in North Carolina is generally down (Figure 7). The greatest declines have generally been in metropolitan areas where the transit share is the highest and in counties suburban to those areas. In both of these cases, rising average incomes have had the effect of increasing ownership more rapidly than availability of transit has had the effect of encouraging the people to use the system. In general, increases in transit use have been in low-income counties with small communities (Figure 7).

Whereas there have been considerable shifts in commuting by mode, the overall effect on trip lengths has been surprisingly small. The average travel time to work in North Carolina has risen only slightly, from 19.1 min in 1980 to 19.8 min in 1990. Commute times are generally longest in suburban counties adjacent to large metropolitan regions (Figures 3, 8, and 9). The 25 counties with the longest commute times in North Carolina range from 22.3 to 33.4 min. These counties commute primarily to Virginia Beach and Newport News, Virginia. Short commute times are associated with both isolated rural economies in which most commuting is highly local and a few large urban areas. The two counties with the lowest overall average travel time to work are, not surprisingly, relatively isolated and self-contained economies.

FIGURE 7 Change in percentage using public transportation, North Carolina counties, 1980 to 1990 (source: U.S. census).

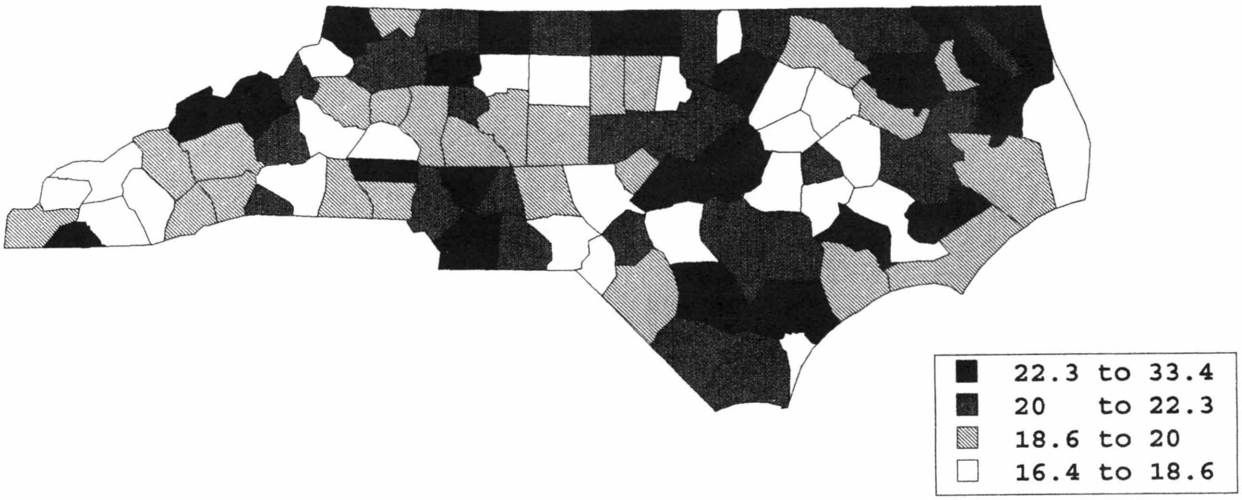

FIGURE 8 Mean travel time to work (min), North Carolina counties, 1990 (source: U.S. census).

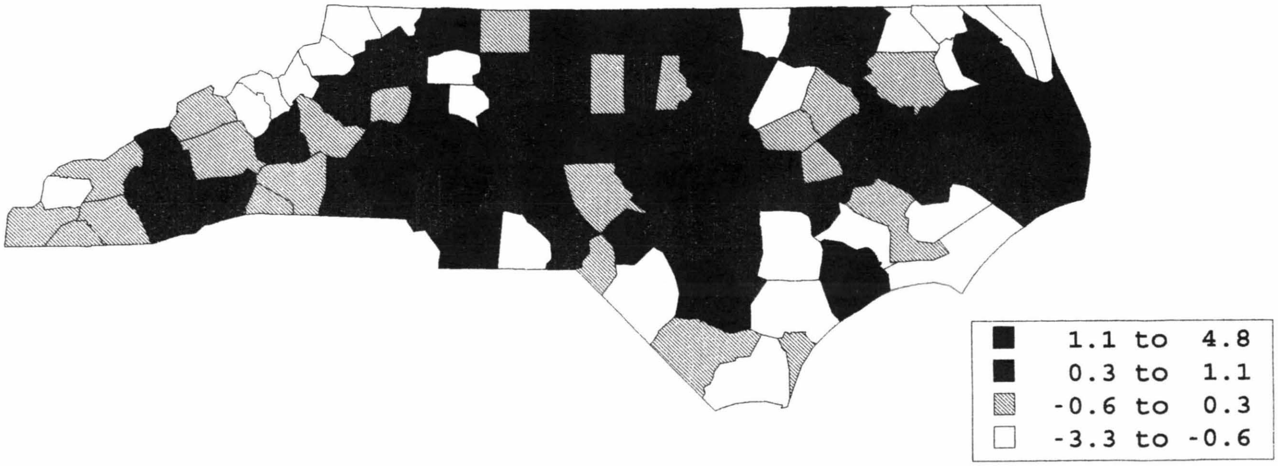

FIGURE 9 Change in mean travel time to work, North Carolina counties, 1980 to 1990 (source: U.S. census).

Carpooling Analysis

Although virtually all counties decreased in carpooling, the magnitude of the reductions has not been uniform by county. County changes in carpooling have ranged from − 16 to + 2.2 percent (Figure 5). Only one county in the state registered an increase in carpooling during the last decade, from a surprisingly high 32.3 percent in 1980 to 34.5 percent in 1990. As Figure 5 also shows, generally the greatest reductions in carpooling were for counties that were modestly high in carpooling in 1980; perhaps surprisingly, some of the lowest reductions in carpooling during the 1980s were also for counties that ranked high in carpooling in 1980. This apparent anomaly can be explained by the underlying structure of economics encouraging carpooling, which is largely income based.

Reductions in carpooling have been greatest in suburban counties surrounding metropolitan areas and in dense metropolitan counties themselves. Generally, counties that are one-tier around the metropolitan regions show the steepest declines, reflecting both changes in accessibility and rapidly rising per capita incomes. Second- and third-tier counties, that is, two circles and three circles back from metropolitan counties, are considerably more isolated and as a result were less affected by overall rises in per capita income or accessibility. The ingredients for high carpooling are relatively low incomes, a shortage of high-paying jobs, and very long commute distances to locations with high-paying jobs. Figure 10 shows a strong relationship between carpooling and per capita income. Generally, as per capita income rises, carpooling percentages fall substantially. Of the many variables tested in our modeling structure, the relationship with per capita income and mean travel times was among the strongest (Table 3). Table 4 and Figure 11 also illustrate a strong relationship between mean travel time and carpooling: for longer commute distances, carpooling is more probable.

DISCUSSION OF RESULTS

Work travel patterns in a county are closely related to its economic structure and that of its immediate surrounding counties. Basically, higher income levels in metropolitan areas attract workers from surrounding counties, thereby increasing commute times and distances, resulting in significant net in-commuting to these magnets. An important side effect is that incomes resulting from such work go to pay for vehicles in the surrounding counties, thereby reducing carpooling and increasing private car commuting. In North Carolina, six large metropolitan areas account for most of the large in-commuting destinations in the state: Charlotte, Raleigh, Greensboro, Winston-Salem, High Point, and Hickory. In each of these areas, net in-commuting exceeds out-commuting by more than 20,000 commuter workers daily. On the other hand, the greatest net out-commuting is from counties adjacent to these large metropolitan regions, the greatest of which experienced net out-commuting of 17,000 workers daily.

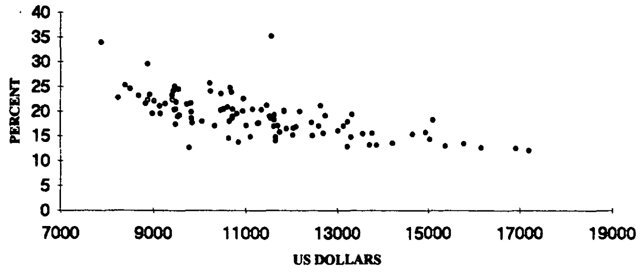

FIGURE 10 Carpooling versus per capita income, 1990.

TABLE 3 Stepwise Regression Model for Percentage Carpooling, 1990

	Value	F
intercept	10.696	7.29
per capita income (000s)	-0.572	6.12
mean travel time '90	0.541	43.17
% 0-car households '90	0.229	4.05
county urban classification	0.301	4.53
population density, '90	-0.00394	2.27

n=100
r squared = 0.67

TABLE 4 Correlations Between Carpooling and Other County Statistics

Percent Carpooling '90		Change In Percent Carpooling 1980-90	
% drove alone '90	-0.86	change in % drove alone '80-90	-0.59
% public transit'90	-0.28	change in % p.t. use '80-90	0.04
% other means '90	0.13	change in % other means	-0.28
% work home '90	0.03	change in % work at home	-0.31
mean travel time '90	0.55	change in mean travel time	0.32
vehicle regist '90	-0.56	percent change in registrations	0.09
Housing units '90	-0.56	change in housing units '80-90	0.06
0-car households '90	-0.54	change in % 0-car HH '80-90	0.08
% households 0-car '90	0.45		
3+ car households '90	-0.58	change in % 3-car HH '80-90	-0.24
% households 3+ cars '90	-0.04		
per capita income	-0.66	per capita income	-0.03
		percent change pop. '80-90	0.05
		1987 employment	0.096
		1987 non-manufacturing employment	0.11
		% manufacturing job change	0.14

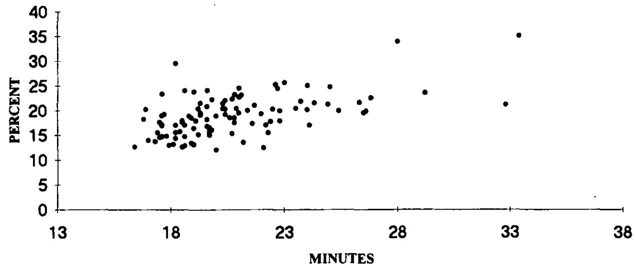

FIGURE 11 Carpooling versus mean travel time, 1990.

Conventional wisdom regarding carpooling—that it is essentially a suburban and urban phenomenon—is incorrect. In fact, carpooling is largely a phenomenon of rural lower-income and isolated regions, not of suburban counties and metropolitan regions (Figures 4, 10, and 11). In suburban and metropolitan counties, carpooling is a lower share of travel than in rural areas. Carpooling is more correctly associated with low income and isolation than it is with traffic congestion and high accessibility.

The reasons for declines in carpooling are many and complex. They are partially attributed to rising incomes, which have put automobiles within the reach of more workers. Perhaps the greatest influence has been increases in labor force participation by women, who have increased both car purchasing and solo driving. Other factors, such as relatively low gasoline prices, slowly declining costs of transportation relative to incomes, and generally increasing accessibility have also contributed to these trends. The energy crisis in 1973–1974 and again in 1979 temporarily lowered overall travel growth but have not substantially changed the basic underlying trend toward increasing private mobility.

It has been long recognized that carpooling, in the aggregate, is the summation of behaviors from different motivations. The traditional carpool markets identified in travel surveys are as follows:

1. Individuals economically driven in commuting environments,
2. Friends and acquaintances who live and work close to each other, and
3. Family members.

The total carpool market from rural counties, though relatively large, is small numerically. Since approximately 30 percent of Americans live in rural environments, it may be useful for studies to begin to review the nature of carpooling from such environments to distant metropolitan regions. People carpool for a variety of reasons, but the greatest proportion of people carpool because of job economics. When jobs are not available and commute distances are long but feasible and income differentials high, carpooling from relatively isolated second- and third-tier counties to metropolitan centers is likely to occur. Ironically, individuals in first-tier counties brought higher incomes home to their suburban counties and bought cars with them. As a result, solo car commuting in those counties increased rapidly.

Travel time's role in carpooling is complex. If travel times are too short and job access is high, the gains from carpool coordination are not worth the hassle. On the other hand, if distances are too great, commute travel will be dampened and carpooling will be low. Moderately long commuting distances, generally in the 40- to 60-min range at the extreme and the 35-min range on the average, appear to be the ideal circumstance for carpooling. Beyond that range, travel times are too great to make the gain in income worth the trip to the city.

The intention of this paper has not been to explain or develop a structure underlying the causality of carpooling, but rather to describe one of the most remarkable shifts in travel behavior ever observed in the United States. We believe that research should turn to the following items:

1. Full documentation, in every state and every county, of the extent of reductions in carpooling;
2. Identification of those few areas in the nation where carpooling has increased, both in real and percentage terms;
3. Thorough behavioral analysis of the structure of carpooling, particularly in rural markets, where it has been virtually unstudied, and particularly in informal family and friend-related markets where our knowledge is extremely weak. Research should cease on how to increase carpooling for those who choose to match their names with other riders and should be accelerated on understanding the behavior of markets perhaps 15 times larger than this one;

Carpooling service organizations need to refocus attention from concern about counting the number of names in data bases to the loss of market share. Serious consideration should be given to reducing or eliminating the present focus of carpooling programs on urban travel. They should be replaced with programs that focus strongly on rural residents who commute long distances to cities. Present employer-focused programs in urban areas should be replaced with residence-based programs in rural areas.

In summary, insistence on the cost-effective expenditure of taxpayer dollars means that all programs, including carpooling programs, should be carefully reviewed. The data presented in this paper suggest that carpooling as a commuting behavior has declined radically in the last 10 years for reasons related to shifts in demographics, accessibility, and income. Government agencies need to understand these trends and assist people in achieving mobility while minimizing energy consumption, air pollution, and congestion. It is clear that present programs to encourage carpooling have not had the desired effect. More cost-effective approaches for achieving the goals rather than concentrating on the means should be explored.

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Publication of this paper sponsored by Committee on Ridesharing.

Ridesharing and the Consumer: A Tale of Two Marketing Strategies

DEBORAH CHUN

Transportation demand management strategies have traditionally been designed to reach commuters with the rideshare message where they work, particularly because of Regulation XV (a regional ordinance that requires employers with 100 or more employees per site to submit a trip-reduction plan annually). As an alternative to employer-site promotions, Commuter Transportation Services, Inc. (CTS) developed and evaluated two consumer-oriented studies to determine the effect of reaching commuters outside the workplace with a ridesharing message. The first is an evaluation of a series of corridor promotions conducted by CTS over a 12-month period. Corridor promotions were designed to target commuters at the home-end with a rideshare message to increase awareness of alternatives to driving alone to the workplace. The evaluation was conducted to determine how effective the promotions were in communicating this message. The second is an evaluation of California Rideshare Week (CRSW), a statewide, employer-based promotion designed to educate the commuting public about alternatives to driving alone. During CRSW pledge cards were distributed to commuters in an effort to encourage them to use an alternative rideshare mode during the week-long campaign. A survey was designed and conducted by CTS to assess the impact of CRSW by measuring commuting behavior before, during, and after the campaign. Results indicate that the two techniques were successful in generating awareness and trial of alternative rideshare modes. However, they need to be conducted concurrently with employer promotions to have lasting impact. This will enable a more targeted message to reach commuters both at the workplace and at home.

Commuter Transportation Services, Inc. (CTS) developed and evaluated two studies to determine the effect of reaching commuters outside the workplace with a ridesharing message. The first is an evaluation of a series of corridor promotions.

CORRIDOR PROMOTION EVALUATION COMPARISON

Background

The marketing and advertising department of CTS designed and implemented seven corridor promotions as a means of marketing ridesharing to drive-alone commuters. A corridor is defined as a segment of a freeway that is used by commuters living in a specific geographic location who drive alone to the work site. To determine the effectiveness of each promotion, an evaluation survey was conducted. This paper compares results of all seven evaluations to assess the effectiveness of this marketing strategy.

Corridor promotions are advertising campaigns that target commuters at home (rather than at work) with the rideshare message. The primary targets of the campaign are commuters who typically drove alone to the work site. The goal was to persuade them to try, and ultimately switch, to a rideshare mode (e.g., carpool, vanpool, transit, walking/bicycling, and telecommuting).

In theory, commuters residing in a geographic location near the targeted corridor are a homogeneous group who will be responsive to a certain message. Assumptions were made that specific benefits would motivate these groups of commuters to try a rideshare mode. Unlike marketing efforts that primarily target commuters through their employers [e.g., California Rideshare Week (CRSW), the state-wide employer-based promotion], these campaigns were designed to market ridesharing directly to commuters by using a combination of media, including brochures, telemarketing phone calls, billboards, and newspaper advertising.

Objectives

There were two objectives for the campaign: to generate increased awareness of the benefits of ridesharing and to motivate commuters to try an alternative rideshare mode instead of driving alone to the work site.

Method

To achieve these objectives, seven corridor promotions were executed over a period of 12 months. For each promotion, a specific geographic area was identified, assumptions were made regarding common characteristics of commuters in the region, and a message was designed to target them. Each succeeding promotion experimented with a specific message, allowing for a learning process whereby previous campaign messages could be improved. Table 1 summarizes the messages and other details of each of the seven promotions.

The effort was extensive. Depending on the corridor, any combination of media was used to promote ridesharing, including brochures, telemarketing phone calls, billboards, and newspaper advertising. The investment totaled more than $450,000 for all seven corridor promotions, ranging from $30,000 (Corridor 14) to $116,000 (10/60 Corridor). The demographic target specifications of age and income were broad based but

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TABLE 1 Corridor Promotion Comparison

	CORRIDOR 10/60 SPRING, 1991	SIMI VALLEY CORRIDOR SPRING, 1991	CORRIDOR 14 FALL, 1991	CORRIDOR 605 SPRING, 1992	CORRIDOR 110 SPRING, 1992	CORRIDOR 15 SPRING, 1992	CORRIDOR 101 SPRING, 1992
CAMPAIGN DESCRIPTION							
Budget	$116,000	$31,160	$30,000	$74,500	$89,000	$48,500	$69,500
Target							
A. Size of Mailing	55,000	14,232	14,000	45,000	51,000	20,256	44,324
B. Demographics							
1. Age	20 - 45	20 - 45	20 - 45	20 - 50	20 - 50	20 - 55	20 - 55
2. Household Income	$25,000 - $80,000	$25,000 - $80,000	$25,000 - $80,000	$20,000 - $100,000	$15,000- $100,000	$20,000 - $100,000	$20,000 or more
Promotion Message	Cash savings	Cash savings: vanpool	General rideshare	Rideshare - The American Way	Six different messages	"I saved money"	Time savings
Media Mix (brochure, telemarketing, billboards, newspaper)	BR,T,B,N	BR,T,N	BR,T	BR,T	BR,T,B	BR,T	BR,T
COMMUTER CHARACTERISTICS							
Average Distance Traveled (one way)	33.7 miles	28.0 miles	32.0 miles	13.3 miles	13.1 miles	23.4 miles	16.9 miles
% rideshare prior to campaign	22%	17%	NA	19%	18%	17%	21%
Awareness of Ridesharing (aided)	67%	77%	60%	54%	61%	63%	69%
CAMPAIGN RESULTS							
Advertising Awareness	57%	29%	51%	37%	45%	46%	44%
Media (Top 3)	1. work/employer 2. radio 3. television	1. work/employer 2. RIDE # 3. radio	1. work/employer 2. RIDE # 3. billboards	1. work/employer 2. blue fwy signs 3. TV	1. work/employer 2. billboards 3. blue fwy sign/TV	1. work/employer 2. blue fwy signs 3. TV	1. work/employer 2. blue fwy signs 3. radio
Message (Top 3)	1. one should rideshare 2. "MOM" campaign 3. RIDE #	1. RIDE # 2. one should rideshare 3. through employer	1. one should rideshare 2. "MOM"campaign 3. RIDE #	1. RIDE # 2. one should rideshare 3. through employer	1. one should rideshare 2. through employer 3. RIDE #	1. one should rideshare 2. through employer 3. RIDE #	1. one should rideshare 2. RIDE # 3. through employer
Total Placements/Switched into Ridesharing							
#	6,762	1,427	1,044	3,411	4,718	1,769	3,528
%	12.8	12.7	10.6	11.4	11.1	10.3	9.3
Placements, Direct[1]							
#	2,747	348	522	1,077	1,445	670	1,252
%	5.2	3.1	5.3	3.6	3.4	3.9	3.3
Placements, Indirect[2]							
#	4,015	1,079	522	2,334	3,273	1,099	2,276
%	7.6	9.6	5.3	7.8	7.7	6.4	6.0

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[1] *Switched from drive alone mode to rideshare mode and recalled advertising/promotion*

[2] *Switched from drive alone mode to rideshare mode and recalled advertising/promotion other than employer-based promotion*

similar for all the corridors. For each corridor promotion, the advertising campaign encompassed a 6-week period.

The regions chosen for corridor promotions covered a variety of corridors throughout the Los Angeles area, and each was assumed to include populations with homogeneous commuting patterns. For example, the 10/60 corridor promotion targeted commuters who live in the San Bernardino/Riverside area and commute to work in Los Angeles County. Since these were long-distance commuters, the message designed for this campaign was "cost savings." In contrast, the 605 corridor targeted commuters who live in geographic areas along the corridor, but, since it was not possible to segment them by length of commute, the primary message was designed to be more general in nature ("Rideshare—The American Way").

Cost saving was also the primary message for commuters targeted in the Corridor 14 (North County) and Corridor 15 (Apple Valley) campaigns. In Corridor 118 (Simi Valley), potential vanpoolers were targeted in conjunction with the marketing of a vanpool subsidy program. For Corridor 110 (South Bay), different potential motivating benefits were tested: six versions of the brochure headline were used ("Smog is Thick Enough," "Work Days are Long Enough," "Traffic is Bad Enough," "Life is Stressful Enough," "Gas is Costly Enough," and "Car Repairs Cost Enough"), but the inside message to encourage ridesharing was the same. "Time savings" was the focus of the 101 (San Fernando Valley) corridor brochure.

The promotions were timed to ensure that they did not conflict with any other ridesharing promotions, such as CRSW. This decision was made so ridesharing messages could be communicated throughout the year instead of having all promotional activity during one time period.

A variety of media vehicles and varying dollar allocations to each medium were used for these promotions: the 10/60 campaign used all four media vehicles (brochure, telemarketing call, billboards, and newspaper); Simi Valley used brochures, telemarketing calls, and newspaper; and Corridor 110 used brochures, telemarketing calls, and billboards. The remaining corridors (14, 605, 15, and 101) used only brochures and telemarketing calls.

Evaluation of Results

To measure the effect of each promotion, pre- and postcampaign telephone surveys were conducted by a market research firm and measured the following factors: commute travel mode, awareness of ridesharing, and changes, if any, in commute travel mode. The presurvey was conducted before the onset of the advertising campaign, and the postsurvey was conducted 6 weeks after the campaign ended. Consequently, a comparison of results between the two surveys identified any changes that occurred during the campaign period. (There was, however, one corridor promotion (Corridor 14) that did not use a presurvey but instead used a test survey and control survey to measure change in travel mode. Respondents from the test survey sample were reached with advertising support, whereas respondents from the control survey sample did not receive any advertising support.)

Sample sizes for the evaluations varied from 350 to 1,000 per survey. The sample was derived from the original list of direct mail respondents. For budget considerations, a choice was made to reduce the sample size in later evaluations, even though this would affect the margin of error. A sample size of 350 yields a 5.3 percent margin of error, whereas a sample size of 1,000 yields a 3.2 percent margin of error. It was believed that the results would still give a good indication of campaign effectiveness.

Results

Advertising Recall

One of the objectives of this campaign is to increase awareness of the rideshare message. The level of achievement was evaluated using two measurements typical of advertising evaluations: (*a*) unaided awareness (asking the respondent where message was seen/heard without any type of cues) and (*b*) aided awareness (providing respondent with cues to determine if advertising was seen/heard in any of the media used).

When asked, on an unaided basis, where they had seen or heard any type of rideshare messages, the top-rated response was consistently through work/employer. This top-of-mind response is twice that of any other top-of-mind response. This is encouraging, since apparently a relatively high level of awareness exists despite the fact that no special coordinated programs at employer sites were conducted concurrently with any of the promotions, other than ongoing employer-based trip reduction programs. (Regulation XV applies to employers with 100 or more employees per work site in the four-county region: Los Angeles, Orange, San Bernardino and Riverside.)

Unaided awareness of the benefits of ridesharing is high to begin with, so the corridor promotions were successful in reinforcing the attributes of these benefits to commuters. This is important since it helps to keep ridesharing as a top-of-mind message. Clearly, some level of regular advertising is required to sustain this awareness.

Virtually all commuters can cite numerous benefits of ridesharing ("reduces pollution/smog," "reduces traffic/congestion," "saves money and gas") on an unaided basis. However, there is a consistent pattern of recalling general messages that were not explicitly stated in the brochure, and not the specific messages that were stated in the brochure. For example, "good for the environment" was a general message recalled in the 110 promotion evaluation, instead of "life is stressful enough" (or one of the other five headlines), which was the specific message highlighted in the brochure.

Further, messages recalled have a pattern of being "societal" concerns, which may not motivate commuters as individuals to change their travel commute mode. Before they are willing to change to ridesharing, commuters may be not satisfied with the answers to "What is in it for me?"

Aided advertising recall reveals results similar to those for unaided recall, with all campaigns showing little increase in levels of message recall between the pre- and postsurvey periods; despite specific campaign messages that highlighted different benefits of ridesharing (e.g., cost savings), commuters

Transportation Demand Management at Small Employer Sites

TORBEN CHRISTIANSEN, LAURA GORDON, AND ROY YOUNG

Mandatory employer-based vehicle trip reduction regulation in Southern California covers only companies employing at least 100 workers at a single site. Attention among regulators and transportation managers is now turning toward smaller work sites (those with fewer than 100 employees), since these sites employ a majority of all commuters. Transportation demand management (TDM) methods appropriate for larger work sites, however, will not necessarily be effective at smaller sites. Commuter Transportation Services (CTS) is involved in a number of studies to learn more about small employer work sites and to design TDM programs appropriate for the small employer market. The annual CTS "State of the Commute" study is a survey of the commuting patterns and attitudes of Southern California commuters. Results from this study reveal some minor but important differences in commuting behavior among those who work at larger sites versus those who work at smaller sites. In a second study, CTS surveyed employers with 25 to 99 employees. By comparing the results of this survey with data from the South Coast Air Quality Management District's data base of large employers, important differences emerge between the status of TDM programs at smaller and larger sites. On the basis of insights generated by these and other studies, CTS has designed a pilot demonstration program to test TDM incentives at small employer work sites in downtown Los Angeles. Results from this pilot will provide further information about the differences in TDM programs at smaller and larger work sites and about the most effective ways of bringing TDM to the smaller sites in the absence of regulation.

In the greater Los Angeles area, under the South Coast Air Quality Management District's (SCAQMD's) Regulation XV, employers with 100 or more employees (larger employers) are required to submit trip reduction plans detailing how they intend to decrease the number of vehicles arriving at their work sites. The main purpose of this requirement is to reduce the air pollution in the region, and it is part of complying with the California Clean Air Act of 1988. Whereas the regulation of larger employers has shown some progress in decreasing vehicle trips, the overall impact of the program on air quality seems limited. Even if the regulation results in its intended goal of a 20 percent reduction of vehicle trips at the larger employer sites, the regulation's potential for drastically reducing air pollution might be limited, although more than 60 percent of the emissions in the area comes from mobile sources. The regulation's potential is limited because it only regulates commute trips and only for larger sites. Commute trips make up approximately one-third of all trips, but since only 40 percent of the area's commuters work for larger sites, only about 13 percent of all trips are subject to regulation.

There are four major reasons for focusing on commute trips in regulations intended to reduce the number of vehicle trips. First, commute trips are more likely to be taken alone than are leisure trips, giving them a greater potential for reduction in vehicle trips without reducing person trips. Second, commute trips are almost by definition repetitive and predictable; changing the behavior once is extremely likely to have an impact on a large number of future trips. Third, commute trips tend to be concentrated in the morning and the afternoon, creating periods of congestion, which leads to lower speeds and more pollution per vehicle mile traveled. Finally, because some of the primary components in vehicle emissions react with sunlight to create smog, trips taken in the morning have a more negative impact on pollution levels than do trips taken at other times during the day.

To focus on larger employers has an immediate appeal because more employees (and thereby more trips) are targeted simultaneously. The problem of targeting smaller employers becomes clear by examining the average number of employees at employers of different sizes. Employers with 100 or more employees (i.e., those who are currently regulated) have an average of 245 employees. For employers with between 25 and 99 employees, the average is 41 employees. Employers with less than 25 employees average only 4 employees. For the SCAQMD, this means that if employers with 25 to 99 employees were included in the regulation, the SCAQMD would have to monitor three times as many employers to reach only 50 percent more employees.

Commuter Transportation Services, Inc. (CTS) is a private, nonprofit organization providing free transportation demand management (TDM) services to most of the area subject to SCAQMD's commute trip regulation. Because of the larger number of employees who can be reached simultaneously, CTS has concentrated its efforts at the larger employer sites. CTS has serviced these sites with a number of account executives establishing a one-on-one working relationship with each site. Because of the large number of commute trips not reached by the current regulation of larger employers, a number of cities in the region began considering their own regulation targeted at smaller sites, and CTS decided that it needed to gain a better understanding of this market.

Experiences from the larger sites had shown that having to comply with a regulation made employers more receptive to the services CTS offers. Even though regulation could be expected to make it easier to reach smaller employers, the uncertainty about when and how trip reduction programs would be mandatory for smaller employers made CTS broaden the scope to also consider how smaller employers can be reached in the absence of regulation.

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not in combination with alternative modes) before CRSW. The survey sample contained 155 commuters whose only travel mode before CRSW was solo driving, representing 34 percent of total respondents. All others used some form of ridesharing before the promotion. An in-depth analysis of those who always drive alone was undertaken to trace their commuting behavior during and after rideshare week.

Mode Profile of Drive Alones During Rideshare Week

Of the 155 respondents who only drove alone before rideshare week, 74 percent (115) used alternative modes during rideshare week. The mode choice of these commuters is given in Table 3. More than fifty percent tried carpooling during CRSW, whereas one-fourth tried some other rideshare mode (bus, vanpool, walk, bicycle, or telecommute).

Mode Profile of Solely Drive Alones After Rideshare Week

Of those who always drove alone before CRSW, 47 percent continued their use of an alternative mode after CRSW ended.

Prior Year Comparison

In 1991, the total 461 survey respondents included 155 drive-alone commuters, representing 34 percent of the sample (compared with 1990 figures of 239 drive-alone commuters out of 602 total representing 40 percent of the total sample).

In both 1990 and 1991, nearly three out of four drive-alone commuters (72 percent in 1990, 74 percent in 1991) tried a rideshare mode during CRSW, as indicated in Table 4.

After CRSW, former drive-alones in 1991 were slightly more likely to continue some form of ridesharing than 1990 former drive-alones (47 versus 40 percent).

Conclusions and Recommendations

1. CRSW has a positive influence on travel behavior. Comparing the commuting behavior of the drive-alones before, during, and after CRSW, the survey found that these formerly drive-alone commuters tried some form of ridesharing during the promotion, and many continued ridesharing after the promotion. Hence, the week-long statewide promotion encouraged these commuters to try an alternative mode and had a positive influence that continued after the CRSW promotion ended.

TABLE 3 Travel Mode of Drive-Alone Commuters During and After CRSW

	DURING CRSW	AFTER CRSW
Drive Alone	26%	53%
Carpool	53%	35%
Bus	10%	4%
Vanpool	3%	2%
Walk	6%	4%
Bicycle	5%	4%
Telecommute	1%	0%
Other	2%	3%
Base:	(155)	(155)

Base: Refers to Drive-Alones prior to CRSW
Note: Total is more than 100 percent due to multiple responses.

TABLE 4 Drive-Alones Before, During, and After CRSW—1991 Versus 1990

	Drive-Alones		Drive-Alones Who Shifted to Rideshare	
	1990	1991	1990	1991
Before (Base)	(239)	(155)	(239)	(155)
During	28%	26%	72%	74%
After	60%	53%	40%	47%

2. Working in conjunction with Regulation XV employer-based trip reduction plans, CRSW can produce the additional marketing stimulus required to increase alternative mode trial and ultimately the number who try and remain in ridesharing arrangements.

3. The 1991 findings indicate that of the 155,000 CRSW pledge card participants, 52,700 (34 percent) were drive-alones before CRSW. Of the 52,700 drive-alones, 38,998 (representing 74 percent) tried alternative modes during CRSW. After CRSW, 24,769 former drive-alones (47 percent) continued in their use of alternative modes. In effect, CRSW converted 24,769 former drive-alone commuters to a rideshare mode.

4. Whereas converting the drive-alones during CRSW is of primary significance, secondary issues that were not included in the 1991 survey need to be incorporated in future survey design: Did ridesharers start ridesharing more often as a result of CRSW? Did two-person carpools become three-person carpools? Did ridesharers who were former drive-alones get their message from employer efforts, radio, ads, and so forth? What were the frequencies of ridesharing before and after CRSW? What CTS services were used during and after CRSW? Also, a larger sample of drive-alones should be used in future research to enhance analysis of drive-alones' commuting behavior.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

1. This paper examined two types of consumer promotions. Each used a different technique to communicate the rideshare message. The corridor promotion raised awareness through traditional communication media (direct mail, telemarketing, newspapers, billboards), whereas CRSW used pledge cards to motivate commuters to change their travel mode.

2. Both techniques were successful in generating awareness and trial of alternative rideshare modes. It is important to continue to emphasize these modes to commuters.

3. Thorough analysis of these two techniques suggests an opportunity to achieve more marked results by developing plans to incorporate these types of promotions in conjunction with employer-based efforts. Traditional consumer-oriented advertising has shown the importance of repeated messages.

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the benefits to the region and, to a lesser extent, of the benefits to individual commuters is high among commuters. To maintain awareness at these levels requires continued and multiple efforts.

2. Multiple media and multiple messages produce reinforced impact. Greater frequency of exposures for any particular corridor promotion is required to make an impression on the targeted commuter.

3. If awareness of personal benefits, such as cash savings or reduced stress, is to be increased to the level of awareness of societal benefits (reduced pollution and congestion), more advertising weight is required. However, the extent to which personal benefits are believable, and, more important, more motivating, is not yet known.

4. In addition to increased and reinforced awareness, these promotions helped to motivate some drive-alone commuters to try a rideshare mode in their commute to the work site. In the short term alone, over the length of the campaign, a sizable number of commuters switched from drive-alone to rideshare commute modes. Still, it is likely that the decision to actually change commute mode is made over a longer period than 6 weeks and is likely to be the result of multiple exposures to advertising messages. Therefore, these campaign evaluations cannot accurately isolate and measure the behavior change generated by one campaign.

5. Apparently there are few actual homogeneous corridors with commuters who travel from specific home-end locations to specific work-end locations. Therefore, the concept of a true corridor promotion using a specific, targeted message that will appeal to a similar group of commuters is limited. Promotions that used a targeted message did not result in higher awareness or higher placement rates than those promotions that did not use a targeted message.

6. The importance of coordinating all marketing efforts with employers is evident. Employers have the advantage of more accurately segmenting the target population with programs that are responsive to specific needs.

7. Neither the awareness of rideshare benefits nor the level of switching to rideshare modes that results from an individual campaign can be accurately measured by a precampaign and postcampaign survey. Campaigns have long-term effects, and they have impact that works in combination with other efforts. These additional positive effects cannot be isolated by any survey evaluation.

Recommendations

1. Ongoing promotions of all types are required to boost awareness of the benefits of ridesharing and trial of ridesharing commute modes. However, broader efforts, in conjunction with employer sites and public relations appeals, will have substantially greater impact than that generated by isolated corridor promotions.

2. Developing a campaign to try ridesharing, even on a part-time basis, can be modeled as a movement (such as the current recycling movement) so it can become the "in" thing to do.

3. It is important to design ridesharing promotions in association with employer sites, since employers are better able to segment their employee base with programs that will appeal to the specific needs of segments of the commuting population.

4. Results from prior research (the CTS annual "State of the Commute" is a survey of commuting patterns and attitudes of commuters in the five-county region of Los Angeles, Orange, San Bernardino, Riverside, and Ventura) indicate an opportunity to tap small employer sites with the rideshare message, because employees at these sites are less likely to be aware of rideshare programs but are more willing to explore rideshare options than employees at larger (100 or more employees) regulated sites.

CRSW EVALUATION, 1991

Background and Objectives

CRSW is a statewide, employer-based promotion designed to educate the commuting public about alternatives to driving alone. The 1991 event was held the week of September 27.

As part of the week-long promotion, CTS distributed 1.4 million pledge cards through employee transportation coordinators at employer sites. (Commuters return cards so they can "pledge" to use an alternative rideshare mode during the week. The pledge cards are subsequently entered into a drawing so commuters can win donated prizes.) Company-sponsored transportation fairs were held throughout the week.

The objective of this research was to evaluate the impact of CRSW. The findings of this survey reveal commuting behavior before, during, and after the 1991 CRSW to highlight the short-run effects of the statewide promotion.

This research focuses on travel mode changes of former drive-alone commuters to determine whether the promotion was effective in influencing trial and adoption of rideshare modes. Tracking the travel behavior of former drive-alone commuters will give the best indication of the success of the promotion. The results for 1991 will be compared with those of 1990 to determine the relative success of the campaign.

One million pledge cards were distributed by CTS in 1990, compared with 1.4 million pledge cards distributed in 1991. A return rate of 5 percent was experienced in 1990 (52,000 pledge cards), which increased to an 11 percent return rate in 1991 (155,000 pledge cards).

The number of pledge cards distributed by CTS in 1991 was 40 percent higher than in 1990. Total pledge cards returned tripled in 1991 from the year before, and the response rate more than doubled.

Methodology

In both 1990 and 1991, a one-page survey was sent 6 weeks after CRSW to 1,200 randomly selected CRSW pledge card respondents. The survey sample consisted largely of employees who sent pledge cards to CTS through their employers. However, it was not determined whether they were full-time or part-time employees.

The survey response rate decreased in 1991 from the 1990 level (50 response versus 38 percent response), but it is still considered a reliable and projectible sample.

Findings

To thoroughly analyze the effects of the promotion, this study examined commuters who exclusively drove alone (that is, are more likely to recall general messages (e.g., one should rideshare).

In terms of media, the level of aided recall was roughly the same for all the promotions, regardless of the media mix used.

For the last few corridor promotion evaluations, commuters were asked, on an aided basis, whether they recall receiving a phone call or brochure about ridesharing. Results were disappointing, with fewer than 1 in 10 respondents recalling both of these communication media.

Placement Evaluation

The second objective of corridor promotions was to encourage trial of rideshare commute modes. Commuters who change travel modes were called "placements," defined as commuters who switched from a drive-alone mode to an alternative rideshare mode within the 6 weeks before the survey. This rate was applied to the target base to calculate the actual number of placements. Placements were then further segmented into direct and indirect placements. Direct placements were defined as respondents who recalled any advertising or promotion (except employer based) for ridesharing within the past 6 weeks. Indirect placements were defined as respondents who only recalled promotions from their employer/work site.

The placements resulting from these corridor promotions represented drive-alone commuters who actually tried an alternative rideshare mode within the past 6 weeks, during each specific promotion. The total placement rate varied by promotion from 9.3 to 12.8 percent of the target base, representing a total of more than 22,000 placements. This is encouraging, since it means that these commuters demonstrated a willingness to alter their commute travel mode to the work site.

In addition, results of these corridor promotion evaluations indicated that a level of switching to rideshare modes from driving alone occurs on an ongoing basis. Some switching may be the result of other past promotions; indeed, in quantifying placements for each promotion, it must be remembered that not all results of the advertising happen within the 6-week campaign period. Of course, some switching may not be the result of any particular promotion effort at all.

For nearly all the corridor promotion evaluations, the resulting direct placement rates were lower than the resulting indirect placement rates, though the differences varied by promotion. This supports the fact that not all rideshare trials can be immediately traced to one campaign over the short life of the campaign. Rather, decisions to change behavior may happen over longer periods of time.

In addition, this confirms the overriding power of employer promotions in influencing commuter travel mode choices and behavior change. Unfortunately, it is not known whether commuters who were surveyed worked for companies that need to comply with Regulation XV, so further analysis is not possible. (The "1992 State of the Commute" survey conducted by CTS found that 90 percent of employees working for large employers were aware of one or more incentives offered to rideshare, whereas only 65 percent of employees working for small employers were aware of incentives offered to them to rideshare.)

In an attempt to explain mode changes, an analysis of the evaluation survey results did not identify any key variables that correlate with rideshare trial rates (unaided or aided advertising recall, commute mode or distance, or money spent on campaign).

For instance, the target of the Simi Valley corridor promotion was to urge commuters to try vanpooling, but results were not consistent. Compared with other promotions, this promotion resulted in the highest level of aided awareness of ridesharing in general, but the lowest level of advertising awareness due solely to the campaign.

Prior research has shown that the longer the commute distance, the more likely a commuter is to rideshare. (The "1992 State of the Commute" survey conducted by CTS found commuters who travel longer distances were more likely to carpool or vanpool.) Therefore, it is not surprising to find higher rideshare rates in corridors with longer-than-average commute distances. It does not follow, however, that placement rates resulting from these special promotions are highest in the corridors with the longest average commute distance. It may be that with already-above-average rideshare rates, additional switching into rideshare commute modes is more difficult to generate. For example, in the 110 corridor campaign, results showed placements in the midrange (11.1 percent), even though these commuters traveled the shortest distances (13.1 mi, one way) of all the promotions; commuters in the Corridor 15 promotion traveled a fairly long distance (23.4 mi, one way), but resulting total placements (10.3 percent) were low.

Overall cost per placement during the 6-week campaign period varied by promotion, ranging from $17.15 for Corridor 10/60 to $28.74 for Corridor 14. Of course, from the survey evaluations, it is impossible to know the final cost per placement after the long-term impact of the campaign has run its course.

The return on the investment in telemarketing in terms of cost per registration also differed by promotion. Table 2 gives the number of commuters who registered for ridesharing and the cost per registrant as a result of the call (information available for spring 1992 campaigns only).

Given the target number of commuters for each promotion, these results seem mixed. As seen, the 605 corridor promotion was the most cost-effective, whereas the 101 corridor promotion was the least cost-effective.

TABLE 2 Commuters Registered and Cost per Registrant

Corridor Campaign	# Registered	Cost per registrant
605 Corridor	1,788	$22.37
110 Corridor	1,159	$49.18
15 Corridor	480	$50.00
101 Corridor	512	$78.13

Conclusions

1. Corridor promotion campaigns were successful in supplementing rideshare messages being communicated in the marketplace through a range of media. Awareness levels of

are more likely to offer compressed workweeks. Twenty-one percent of large sites offer 4/40 or 9/80 schedules, as opposed to 12 percent of small sites. Interestingly, among large sites that offer compressed workweeks, only 17 percent of employees participate, compared with 29 percent for small sites.

Ridesharing Incentives

Few small employers currently have any kind of well-rounded program for encouraging their employees to rideshare. Table 6 indicates that 63 percent of the employers offer no ridesharing services or incentives whatsoever and that a total of 86 percent offer no more than two services/incentives. The largest of the small employers, those with 75 to 99 employees, are somewhat more likely to offer ridesharing incentives. However, their trip reduction programs are still modest compared with those of larger, regulated employers, which offer an average (median) of six different ridesharing incentives to their employees. Small employer sites whose parent company is subject to Regulation XV or Rule 210 are more likely to offer incentives than sites that do not have regulated parents (64 percent versus 56 percent).

Table 7 gives specific incentives and the percentage of sites offering them, and Table 8 gives the same breakdown for sites with and without regulated parent companies.

TABLE 6 Number of Incentives Offered, by Employer Size

No. of incentives offered	% of Sites (by number of employees) 25 to 99	75 to 99	Over 100 *
0	63%	53%	0%
1	14%	15%	1%
2	9%	10%	4%
3	6%	6%	4%
4	3%	6%	9%
5 to 12	5%	10%	82%

* Source: SCAQMD Reg. XV Trip Reduction Plan Database

Company Car

Most employers (69 percent) say that they do not have any company vehicle that could be used for a guaranteed ride home (GRH) program. Small employer GRH programs, therefore, will probably have to rely more on taxis, rental cars, or joint GRH programs with other employers.

Ridesharing Services Desired

To assist CTS in designing a package of services that small employers will be most likely to use, respondents were asked the following question: If you were required to assist your employees in making their commute easier, how likely would you be to use the following free, or low cost, services?

Whereas 18 percent of the respondents did not think that they would be likely to use any services, 54 percent said that they would use at least five of the nine services listed. The most popular among the proposed services was brochures for employees (Table 9). Half of the respondents said they would be very likely to use brochures, and more than three-fourths said that they would be very or somewhat likely to use them.

Again, it must be remembered that these responses, for the most part, represent attitudes before the actual institution of trip reduction requirements.

Languages Required

Fifty-five percent of the respondents said that they would need materials in Spanish as well as English. This percentage was even higher for sites with 50 to 99 employees and for restaurants and manufacturing sites. No other foreign language generated a response rate of more than 3 percent. Clearly, then, all materials designed for general employee use should be made available in English and Spanish.

However, all of the interviews for this survey were conducted in English, and there were only three or four cases in

TABLE 7 Incentives Offered, by Employer Size

	% of Sites Offering 25 to 99	Over 100 *
Assist in forming car/vanpools	17%	69%
Provide rideshare information	17%	63%
Provide preferred parking spaces to ridesharers	12%	73%
Provide bus route and schedule information	11%	42%
Offer use of company car during the day to ridesharers	11%	not avail.
Provide free/low cost parking only to ridesharers	8%	6%
Give each employee a monthly allotment to reduce commuting costs	6%	1%
Subsidize ridesharers	5%	75%
Sell bus passes	5%	not avail.
Register employees with CTS or similar organization	4%	44%
Have contests/prizes for ridesharers	3%	58%
Other	1%	83%

* Source: SCAQMD Reg. XV Trip Reduction Plan Database

TABLE 8 Incentives Offered, by Parent Company's Regulation Status

	% of Sites Offering	
	Parent Regulated	Parent not Regulated
Assist in forming car/vanpools	22%	16%
Provide rideshare information	26%	16%
Provide preferred parking spaces to ridesharers	14%	11%
Provide bus route and schedule information	18%	10%
Offer use of company car during the day to ridesharers	11%	11%
Provide free/low cost parking only to ridesharers	9%	8%
Give each employee a monthly allotment to reduce commuting costs	8%	6%
Subsidize ridesharers	6%	4%
Sell bus passes	7%	4%
Register employees with CTS or similar organization	6%	4%
Have contests/prizes for ridesharers	6%	3%
Other	2%	1%

TABLE 9 Likelihood of Using Rideshare Services

	% of Sites Likely to Use	
Proposed Service	Very Likely	Somewhat Likely
Brochures for employees	50%	26%
"How To" reference manual	44%	25%
Information hot-line phone number	40%	25%
Matching service to help employees find carpool partners	35%	28%
Self-implementation kit	31%	25%
Training program on setting up commuter transportation programs	23%	25%
Videos	23%	23%
Easy to use computer programs	20%	18%
Work with a consultant	18%	18%

which interviews could not be conducted because of a language problem. It is entirely likely, therefore, that English alone may be sufficient for materials to be used only by transportation coordinators or managers.

FINDINGS AND CONCLUSIONS FROM THE SMALL EMPLOYER STUDY

The small employer survey provided information and insights that will be useful in targeting the small employer market.

Strategies To Reach Small Employers

- The majority of small employers are located in multitenant sites with a single property owner, so it may be worthwhile developing programs geared toward tenant groups.
- It may be useful to work with local chambers of commerce as a way of reaching small employers, since well over half of the small businesses surveyed belong to a chamber of commerce.
- Small employers whose parent companies fall under Regulation XV or Rule 210 trip reduction requirements may be a productive market to target, since they are more inclined than other small employers to offer ridesharing incentives, but they still appear to offer far fewer incentives than their regulated parent companies offer.

Strategies To Market to Employers

- Communications to small employers on the benefits of commute management programs should stress how such programs can boost productivity and morale and reduce absenteeism, since these are the three employee issues that small employers consider most critical to their success.
- Brochures or other communications geared toward employees should be provided in Spanish as well as English; communications designed specifically for employers can be provided in English only.
- Potential services receiving the most interest include brochures for employees, "how-to" reference manuals, an information hot line phone number, and ridematching services. Self-implementation kits, training programs, videos, and easy-to-use computer programs also generated favorable responses.

Strategies To Market to Employees

- Most employees who work for small employers park free, so there may be great potential for reducing solo driving through parking management and parking pricing strategies.
- Transit may be an option for many employees at small employer sites, since most small employer sites are extremely accessible to transit.
- There may be potential to reduce commute trips through compressed workweeks and telecommuting, since only a small percentage of small employers currently offer these alternative work arrangements.
- Small employer sites tend to have mostly full-time employees who report to work between 6:00 and 10:00 a.m. These factors should support the formation of permanent carpool and vanpool arrangements among employees at small employer sites.

DESCRIPTION OF PILOT PROJECT

On the basis of the employer-level data provided by the small employer survey and the employee data from the State of the Commute survey, CTS designed a pilot demonstration project to test a trip reduction program for small employers. The pilot will provide data on the effectiveness of trip reduction incentives at smaller employer sites and will help in designing programs geared toward small employers. Funding for the demonstration project has been provided by a government grant paid for by a surcharge on California vehicle registration fees. The pilot is expected to begin in fall 1992.

In designing the pilot, CTS considered what would be the most effective way of reaching commuters who work for small employers. In the future, developing trip reduction programs separately for each small employer will probably not be cost-effective either for the companies themselves or for the regulators; grouping small employers together should lead to substantial economies of scale. The small employer survey revealed that 61 percent of small employers are located in multitenant sites (either multitenant buildings, industrial parks, or malls), where all small employers at a single site could be included in a single trip reduction program. For these reasons, CTS decided to test a building-based approach to reaching small employers.

The pilot project will establish year-long trip reduction programs in two downtown Los Angeles multitenant buildings with large numbers of small employer tenants. An ETC has been hired to develop and implement trip reduction plans for both buildings.

The trip reduction plans will include distribution of subsidized transit passes, a GRH program, rideshare matching services, assistance in carpool and vanpool formation, and various marketing and communications elements, including promotional events, newsletters, and brochures. A parking pricing element may also be included. If implemented, the parking pricing strategy will include variable parking charges, depending on the number of occupants in each vehicle, to further discourage solo driving.

In addition to administering the building-wide trip reduction plans, the ETC will work with individual employers in the buildings to help them in developing their own trip reduction incentives for their employees.

Results of the program will be monitored through surveys of average vehicle ridership, mode split, individual employer incentive programs, and employee attitudes before, during, and at the conclusion of the pilot program. From the surveys, data will be compiled on the effectiveness of each of the trip reduction incentives in reducing vehicle trips. An assessment will also be made of the effectiveness of the marketing methods used for reaching small employers and their employees. This information will then be incorporated into "how-to" manuals and generic marketing materials that can be used by building owners and small employers.

The pilot demonstration project approach was chosen because it can lead to fast replication of facility-based small employer TDM programs on the basis of the success of fine-tuning a tangible program. Small employers are likely to become subject to trip reduction regulation over the next few years, and they will be especially challenged to find ways to comply with these ordinances in a cost-effective manner. Insights and data obtained from this demonstration project should prove valuable in guiding future facility-based or other group-based trip reduction programs for small employers. This project will also help SCAQMD assess the most appropriate and effective role for building owners and managers in the trip reduction process.

METHODOLOGY

Data for the small employer study were obtained through 1,145 completed telephone surveys. From June 4, 1991, to June 14, 1991, interviewers from Lexi International (a Los Angeles–based telemarketing company specializing in the employer market) contacted personnel managers at companies with less than 100 employees located within Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties.

The questionnaire was pretested and programmed into a computer-assisted telephone interviewing system, which ensures adherence to skip patterns and allows for extensive quality control.

A sample of 10,000 companies was randomly selected from Dun & Bradstreet's business list. The Dun & Bradstreet file contained information on company age and industry, which was used together with the survey data.

ACKNOWLEDGMENTS

This study was prepared through grants from the United States Department of Transportation, Federal Highway Administration, with the cooperation of the State of California, Department of Transportation.

Publication of this paper sponsored by Committee on Ridesharing.

State of the Commute in Southern California, 1992

CHERYL COLLIER AND TORBEN CHRISTIANSEN

The 1992 State of the Commute survey, conducted by Commuter Transportation Services (CTS), is based on a telephone survey of 2,512 commuters residing within Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties. The survey provides updated information on commuters' travel behavior and attitudes toward the commute, traffic congestion, alternative travel modes, employer transportation programs, and high-occupancy vehicle lanes. Data obtained from the 1992 survey are compared with those obtained from CTS's previous State of the Commute surveys to uncover changes in behavior and attitudes. With the presence of the South Coast Air Quality Management District's Regulation XV and the Ventura County Air Pollution Control District's Rule 210, it is expected that the increased attention given to air quality, alternative travel modes, and work schedules by the media and at employer work sites will result in changes in travel behavior and attitudes.

Information obtained from the 1992 State of the Commute survey includes work trip time and distance, arrival and departure times, stops made en route, work schedules, transportation modes, vehicle availability, parking costs, awareness and participation in employer transportation programs, employer size, park-and-ride lot usage, and carpool characteristics. Demographic data gathered include age, sex, ethnicity, occupation, years at the work site and residence, number of household vehicles, home and work counties, and household income.

The survey also gathered information on freeway usage, use and attitudes toward HOV lanes, use of alternate routes, availability of transit, perceptions of traffic conditions and changes in those conditions over time, availability and participation in alternative work schedules and telecommuting, commute satisfaction, commute stress, ridesharing experience, commuter concerns, willingness to try alternative travel modes in the face of changing traffic conditions, and recognition of a RIDE-number.

The basic methodology for all State of the Commute surveys was the same. Randomly generated telephone numbers for the region were obtained through Survey Sampling, Inc. Data were gathered through a telephone survey conducted by an outside marketing research firm. For purposes of clarification, data for the 1992 survey were collected from October through November 1991. Analysis and reporting of the data occurred in the spring of 1992. The timing for data collection has remained consistent for all survey years.

The Southern California region has experienced population growth from 1991 to 1992. Regional growth was 2 percent, and in the counties of Riverside and San Bernardino, growth rates were even higher. Regional population has increased by 892,000 since 1989. According to the California Department of Finance, 14.8 million people now consider the Southland home. It is estimated that there are more than 6.8 million commuters in the region.

FINDINGS

The two most significant changes from the previous surveys to 1992 have been an increase in part-time ridesharing (1 or 2 days per week) and a dramatic jump in awareness of employer trip reduction programs.

Travel Behavior and Trends

- Primary (3 or more days per week) travel mode: In 1992, 77 percent of commuters drive alone to work on a regular basis, 14 percent carpool, 5 percent ride the bus, 2 percent walk, 1 percent vanpool, and 1 percent bicycle. Although consistent with 1991 travel modes, this represents a significant decrease in the percentage of commuters driving alone to work compared with 1989 travel data.
- Part-time ridesharing: There has been a significant increase in the percentage of commuters using transportation alternatives once or twice a week. Nearly one-third of all commuters now use an alternative to driving alone at least once a week (Figure 1).
- Travel distance: For all respondents in 1992, the mean travel distance to work is 16.6 mi one way, whereas the median travel distance is 10 mi. Travel distances within the last 3 years have remained virtually unchanged.
- Travel time: In 1992, the average travel time to work is 36 min. The average travel time home is 40 min. The majority of commuters (60 percent) do not believe that their commute time is longer now than it was 1 year ago.
- Arrival and departure times: Thirty-four percent of 1992 respondents are at work before 7:30 a.m., and 56 percent leave work before 5:00 p.m. Commuters are reporting to work and leaving work earlier in 1992 than they did in 1989.
- Carpools: The average carpool has 2.7 members. Fewer than half (43 percent) of carpool partners are household members. Carpoolers report having been in their current carpool an average of 2 years. Carpoolers travel a mean distance of 22 mi to work.
- Bus riders: Riders report they have been riding the bus an average of 4 years. All respondents (except current bus

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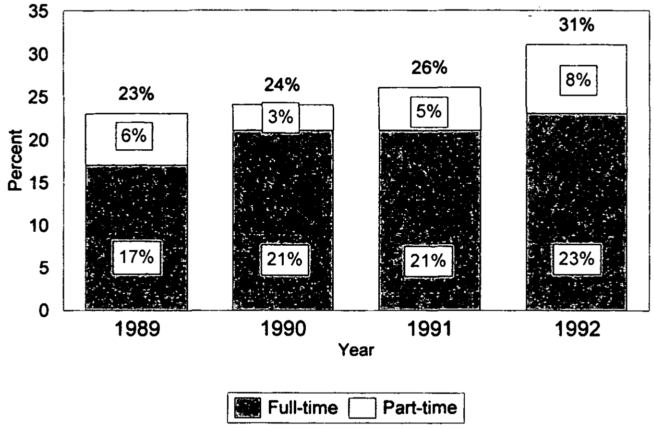

FIGURE 1 Full- and part-time ridesharing.

riders) were asked whether there was a bus that they could take to get to work. Thirty-six percent answered affirmatively. Bus riders travel a mean distance of 12 mi to work.

- Stops during the commute: Nearly one-fifth of all respondents mention that they had made a stop on the way to work. Of these, 23 percent stopped to take their child to daycare or school, and another 21 percent stopped to eat. Twenty-four percent of area commuters stopped on their way home from work, with one-quarter stopping to buy groceries or go shopping. More commuters made stops on their return trip home than did on their trip to work. These data are comparable with previous study findings.
- Number of motorized vehicles: Respondents have a median of two motorized vehicles per household. Motorized vehicles include automobiles, trucks, vans, and highway motorcycles owned or leased by the household. Only 4 percent of the respondents report having no vehicles available.

Commuter Awareness of Employer Transportation Programs

Awareness of incentive programs used by employers to encourage employees to use alternative travel modes or work schedules has increased significantly from 1991 (Table 1). In 1992, 74 percent of all commuters were aware of being offered at least one rideshare incentive; in 1991 that figure was 50 percent. Commuters employed at sites with 100 or more employees (i.e., sites subject to regulation) are even more likely to be aware of incentives (90 percent compared with 65 percent for commuters working at the smaller sites).

Alternative Work Schedules

Forty-two percent of area commuters report that their employer offers flexible work hours, in which 75 percent participate. Fifteen percent claim that their employer offers a 4/40 workweek, in which 48 percent participate. Eleven percent report that their employer offers a 9/80 workweek, in which 47 percent participate. Eight percent of area commuters say that their employer offers a 3/36 workweek, in which 38 percent participate. Fifteen percent of all respondents say that they are currently on either a 4/40, 9/80, or 3/36 work schedule. The percentage reporting that the employer offers flexible work hours has increased significantly (7 percent) from last year's survey. The participation rate in alternative work schedule arrangements has remained unchanged from last year.

Employer Incentives

The employer transportation programs of which commuters were most likely to be aware include the following: offers flexible work hours (42 percent), provides a guaranteed ride home in the event of an emergency (34 percent), provides ridesharing information (33 percent), assists in forming carpools/vanpools (31 percent), provides preferential parking (25 percent), provides bus information on routes and schedules (19 percent), and registers employees with Commuter Computer (18 percent).

Those aware of the programs offered to them were asked whether they have used any of the programs. Forty-one percent of commuters have requested assistance in forming carpools or vanpools, 41 percent have used ridesharing information, 41 percent have made use of ridesharing subsidies, 41 percent have made use of transit route and scheduling information, 40 percent have taken advantage of preferential parking, and 37 percent have registered with a ridesharing organization.

When asked whether participation in the program influenced travel mode choice, roughly one in six answered affirmatively. Those programs most influential in bringing about a change in travel behavior were use of a company car during the day for ridesharers (36 percent), guaranteed ride home program (28 percent), and rideshare subsidies (18 percent).

Telecommuting

Eleven percent of the respondents claim that they have the opportunity to work at home instead of their regular place of work. This figure has remained virtually unchanged during the past 4 years. Of those with the opportunity to work at home, 83 percent actually do.

HOV Lanes

Fifty-three percent of commuters use a freeway to get to or from work. Of these, 35 percent have HOV lanes available to them. Of this subgroup, 28 percent actually use the lanes.

Of the respondents with no HOV lanes available to them, 73 percent believe that the availability of these commuter lanes encourages carpooling, vanpooling, or taking the bus. This figure is even higher for those with access to HOV lanes. HOV lanes are strongly seen as an encouragement to rideshare both by those with access to HOV lanes and those without access.

Attitudes Toward Traffic and the Commute

- Perceptions of traffic: Commuters consider freeway traffic worse than street traffic and evenings worse than mornings.

TABLE 1 Awareness by Employees of Employer Transportation Programs

Employer Program	1989 %	1990 %	1991 %	1992 %
Offers Flexible Work Hours	32%	42%	35%	42%
Offers 4/40 Work Schedule	NA*	14	13	15
Offers 9/80 Work Schedule	NA*	7	9	11
Offers 3/36 Work Schedule	NA*	NA*	NA*	8
Assists In Forming Carpools And Vanpools	8	26	25	31
Provides Ridesharing Info	14	28	22	33
Guarantees A Ride Home In Case Of An Emergency	32	19	17	34
Provides Preferred Parking Spaces To Ridesharers	11	16	13	25
Registers Employees With Commuter Computer	11	14	10	18
Provides Bus Information On Routes And Schedules	12	14	11	19
Provides Free/Low Cost Parking To Ridesharers	10	11	9	16
Subsidizes Ridesharing	NA*	8	9	15
Sells Bus Passes	4	6	7	10
Offers A Company Car During The Day To Those Who Rideshare	19	6	6	8
Has Contests/Prizes For Ridesharers	3	6	6	14
Gives Each Employee A Monthly Allotment Of Money To Reduce Commuting Costs	NA*	4	6	12

* NA = Not Asked in the survey

Roughly 16 percent consider freeway traffic during their commutes to be always good, and approximately 27 percent consider street traffic to be always good.

- Satisfaction with the commute: On a satisfaction rating scale of 1 (low) to 9 (high), respondents give their morning commute a mean (average) rating of 6.1 and their evening commute a rating of 5.9. Somewhat surprisingly, 19 percent of area commuters gave their commute a 9 (the highest) rating (this was true for both the trip to work and the trip home). The range of satisfaction between the morning and evening commutes has definitely narrowed over the past 2 years, since commuters in 1992 were more apt to rate their trip home higher and their trip to work lower than commuters in 1989.
- Commute stress: Commuters were asked to rate the level of stress of their commute from 1 (least stressful) to 9 (most stressful). Overall, commuters rated their commute 4.5. Twenty percent rated their level of stress as 1 and only 9 percent rated their level of commute stress as 9.
- Impact of commute on work relocation: Of commuters who have switched work sites in the last 2 years, 25 percent cited at least one commute-related issue as a reason for the change.

CONCLUSIONS

Findings from the State of the Commute studies are used to support regional policies and suggest rideshare marketing strategies. In addition, the data are being used to support analyses of specific market segments, such as the small employer market and the Hispanic market. Among the policy recommendations from the 1992 State of the Commute are the following:

- Delay lowering the threshold for employer trip reduction programs to include sites with less than 100 employees. Evidence suggests that regular ridesharing (3 or more days per week) is already occurring at sites with less than 100 employees to the same degree that it is occurring at the larger sites (those already under regulation).

- The cost of commuting in the Southland is relatively low. Not surprisingly, commuting costs ranked sixth (representing only 5 percent of commuters) as a motivational factor for travel mode choice. Most commuters (94 percent) receive free parking at their work sites. When commuters cite commute-related reasons for a change in employment location, only 2 percent report costs as the underlying factor. Employer trip reduction programs will only bring about a moderate change in travel mode as a result. To bring about the most change in alternative mode usage, regional policies must support employer trip reduction programs together with pricing strategies, expansion of alternative travel mode options, and improvement in existing options.
- Since part-time ridesharers are less likely to be ridesharing with a person from a matchlist than are full-time ridesharers, this represents an opportunity for matchlist providers to better suit part-time ridesharers' needs.
- One out of four commuters switching work sites in the last 2 years cited at least one commute-related issue as a reason for the change. This represents a sizeable market affected by the stress and strain of the daily commute. Increased education about alternative travel options and incentives may help to keep these employees at their work sites longer.

ACKNOWLEDGMENTS

This study was prepared through grants from the United States Department of Transportation, Federal Highway Administration, with cooperation of the California Department of Transportation.

Publication of this paper sponsored by Committee on Ridesharing.