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Contents

Distribution of Bus Transit On-Time Performance

Richard P. Guenthner and Kasimin Hamat

One method of improving the effectiveness of a bus system is to improve schedule reliability. In evaluating the effect of different strategies to improve reliability, the distribution of bus arrival times in relation to the scheduled arrival times of the buses (adjusted arrival time) is needed. Consequently, an analysis was made to find the distribution of on-time performance. Data were collected from the Milwaukee County Transit System (MCTS) for this study. The results showed that adjusted bus arrival times tend to follow a gamma distribution. This finding differs from the ones that had been proposed in the past. In addition to this finding, adjusted arrival times were examined in relation to the distance along a route, the location of the peak load point, and the headway. Buses in the morning and evening peaks tend to arrive late. However, the midday buses tend to arrive early.

A business must have a market in order to exist. To have a market, it must provide services or products that meet customers' needs. An insufficient understanding of customers is one of many reasons that a business or industry cannot survive or operate competitively. Regardless of the industry, service, or product, quality control is needed ultimately to satisfy the customers. In any service industry, customers are concerned with convenience, service cost, and service performance. However, one of the most important measures of quality of service performance is on-time performance. That is why on-time performance has been widely used as a slogan or trademark by service industries to promote their services. In addition to this marketing aspect, on-time performance is used to reduce cost. But is on-time performance important in the bus transit industry? From a preliminary survey, Bates (*1*) showed a universal agreement among transit operators that on-time performance is an important aspect of transit operations (see Table 1). His survey also demonstrated strong support for research in this area (see Table 2).

Many factors, such as the availability of seats, crime, and maintenance of vehicles, influence people's decision on whether to use bus transit regularly. However, one very important factor is passenger waiting time. A shorter waiting time will make people more likely to ride buses or to become regular riders.

One way to minimize passenger waiting time is to have reliable bus schedule time adherence. Turnquist (*2*) found that once regular passengers are confident that the bus will arrive on time, they can plan their arrival at the bus stop so as to be there just before the bus arrives.

In addition to attracting more riders, on-time performance is important for planning bus headways. This could result in reductions not only of passenger loading variations but also of operating costs. The relationship between bus headways and passenger loading variations was shown by Shanteau (*3*). He concluded that, if the coefficient of variation of bus headways exceeds about 0.30, unequal headways contribute almost exclusively to the variability of loads on buses. That is, headways are poorly controlled. If this is the case, he suggested that bus operators should invest in control strategies to reduce the variance in headways.

DEFINITION OF ON-TIME PERFORMANCE

On-time performance is defined as a bus arriving, passing, or leaving a predetermined bus stop along its route within a time period that is no more than x minutes earlier and no more than y minutes later than a published schedule time. The values of x and y vary across the transit industry. However, one minute and five minutes are the most common values used informally for x and y, respectively (*1*).

This study's main focus is on-time performance, not reliability. On-time performance differs from reliability. For example, if a period of one minute early to three minutes late is defined as on time, a four-minute-late bus is considered to be not on time. If the bus is always four minutes late, however, the consumer might consider this to be very reliable service.

CAUSES OF POOR ON-TIME PERFORMANCE AND STRATEGIES TO IMPROVE IT

To identify poor on-time performance on any route, data from that route should be collected. The data taker can be stationed at a stop or on the bus. Or automatic vehicle monitoring might be used for less costly, more accurate, and more comprehensive data. The data can then be examined briefly to see whether that route has problems concerning on-time performance.

After the routes or systems with poor on-time performance have been identified, the causes for this need to be explored. First, the nature of the problem needs to be categorized. For example, a route that is consistently late must be treated differently from one that is unpredictably late, early, or on time.

Possible causes for poor on-time performance may be as follows:

R.P. Guenthner, Professional Engineering Consultants, P.A., 1440 East English Street, Wichita, Kans. 67211. K. Hamat, Greenfield, New South Wales 2176, Australia.

Variable Ridership

If the route's ridership, for some reason, has large day-to-day changes, the bus might be found to be early on the days of low ridership and late on peak ridership days.

Increased Ridership

If the ridership has increased since the latest schedule revision, then the bus may be found to be consistently late.

External Factors

One example of this may be at a railroad grade crossing. A long or slow freight train is unpredictable and can cause extremely long delays.

Variable Heavy Traffic

Scheduling can be adjusted around consistent heavy traffic. If traffic conditions are variable, however, then the exact arrival times of buses will be very difficult to guarantee. Bus priority techniques may be a solution.

Lack of Schedule Control

Operators need to be sure that buses stay on time. If they do not, better control is needed.

TABLE 1 HOW IMPORTANT IS ON-TIME PERFORMANCE (*1*)?

	Number	Total %	Adj %
Not Important	1	0.7	0.7
Important	37	25.3	25.9
Moderate Important	1	0.7	0.7
Very Important	50	34.2	34.9
Highly Important	8	5.5	5.7
Extremely Important	12	8.2	8.4
Critical	7	4.8	4.9
Essential	27	18.5	18.9
Subtotal	143	97.9	100.0
No Response	3	2.1	-
Total	146	100.0	-

TABLE 2 IS RESEARCH NEEDED (*1*)?

	Number	Total %	Adj %
Yes	90	61.6	70.3
No	38	26.0	29.7
No Opinion	18	12.4	-
Total	146	100.0	100.0

Impossible Schedule

The times presented on a printed schedule may be unreasonable goals. If the system is otherwise operating on time, revising the schedule may solve the problem.

Depending on the nature of the problem, a number of strategies can be used to improve on-time performance. These may be divided into two general categories: (1) adjusting the schedule to reflect the service and (2) adjusting the service to meet the schedule.

Adjusting the schedule may include changed time points, added schedule slack, or longer or shorter layover periods. Adjusting the service could include increased monitoring, longer or shorter routes, fewer stops, express service, or bus priority treatments, such as exclusive lanes or signal preemption.

Abkowitz and Tozzi (*4*) summarized recent research toward methods to measure, evaluate, and improve service reliability. The reader should refer to this work for further details.

DISTRIBUTION OF ADJUSTED ARRIVAL TIMES

Adjusted arrival time is defined in this paper as the difference between the actual or observed arrival time and the scheduled arrival time at a bus stop along a route. In the present research, the distribution of adjusted arrival times is studied. This distribution can be used to (1) measure on-time performance using a significantly smaller sample size, (2) estimate the probability of a bus being on time, and (3) model passenger waiting times, passenger arrivals, and on-time performance. Different strategies can then be either implemented or simulated to evaluate the effects or potential effects relating to on-time performance.

Turnquist (*2*) developed a methodology for estimating passenger waiting time as a function of the variation of bus arrival times. In developing this theory, he suggested that the distribution of bus arrival times at a point is log normal. Guenthner and Sinha (*5*) later used Turnquist's theories to determine average passenger waiting times as an intermediate step in evaluating performance.

Bates (*1*) found that the determination of on-time performance appears to be a largely informal practice with little statistical basis. Consequently, Talley and Becker (*6*) proposed that the exponential probability distribution be used to compute the probabilities that buses on a particular route arriving at a given bus stop will be more than x minutes early and more than y minutes late. They divided time interval data for buses into two groups: those regarding lateness and those regarding earliness. The Kolmogorov-Smirnov goodness-of-fit was performed to make inference to the null hypothesis that the samples used were taken from an exponential probability distribution. The null hypothesis could not be rejected for the late or early time intervals. Consequently, using the exponential distribution, the probability that buses will be more than b minutes late is expressed as follows:

$$\text{Prob}\ (y > b) = e^{-ab} \tag{1}$$

where

e = the base of natural logarithms,
$a = 1/u$, and
u = arithmetic mean of the values of y in the sample.

The same formula is also proposed with respect to early arrivals.

Turnquist (*2*) dealt more with the passenger waiting times, for random and nonrandom arrivals, and with the proportion of nonrandom arrivals than with bus transit on-time performance. However, his work showed the important relationship between service reliability and passenger dwell time. Talley and Becker (*6*) were the first ones who analyzed on-time performance with a statistical basis. Their analysis separated earliness and lateness. On-time buses were included in both samples. This approach is useful in many ways. It has difficulty, however, in terms of predicting the probability of on-time bus arrivals.

In the present study, the samples were not divided into early and late. In addition, data were recorded in seconds, which was deemed to be most accurate since the probability distribution of bus arriving times is a continuous distribution.

ROUTE SELECTION

Data for this study were recorded by observing buses from the Milwaukee County Transit System (MCTS), which serves Milwaukee County, Wisconsin, with a 1980 population of 964,988. This system operates sixty-six routes, nine of which are express. A grid system of routes is used and encouraged by a free one-hour unlimited use transfer. MCTS charges a flat fare.

Routes 10, 23, 30, and 31 were chosen to collect the on-time performance data. These routes were used because all of them pass through downtown Milwaukee and through a common point (12th Street-Wisconsin Avenue). In addition, all the buses of these routes travel a distance long enough to be considered suitable for data collection for the analysis. Bus stops located near the 12th Street-Wisconsin Avenue intersection were the main points selected for collecting the data (see Figure 1). A time point, 12th Street is near the maximum load point for most of the routes. All the buses of the chosen routes, eastbound and westbound, pass by these stops except eastbound buses of Route 10, which pass by the bus stop at 12th Street-Wells Street, one block to the north (see Figure 1).

To examine on-time performance as a function of distance along the route, bus stops at the County Hospital and at Jackson Street-Wisconsin Avenue were also used to collect data for Route 10 analysis only. The stop at Jackson Street-Wisconsin Avenue is the east end of Route 10. The County Hospital is the west end of one of two branches of Route 10. Only the arriving times were gathered at these stops. The approximate bus running-time from Jackson Street-Wisconsin Avenue to 12th Street-Wisconsin Avenue is 10 minutes. The time from 12th Street-Wisconsin Avenue to the County Hospital is 23 minutes (see Figure 2).

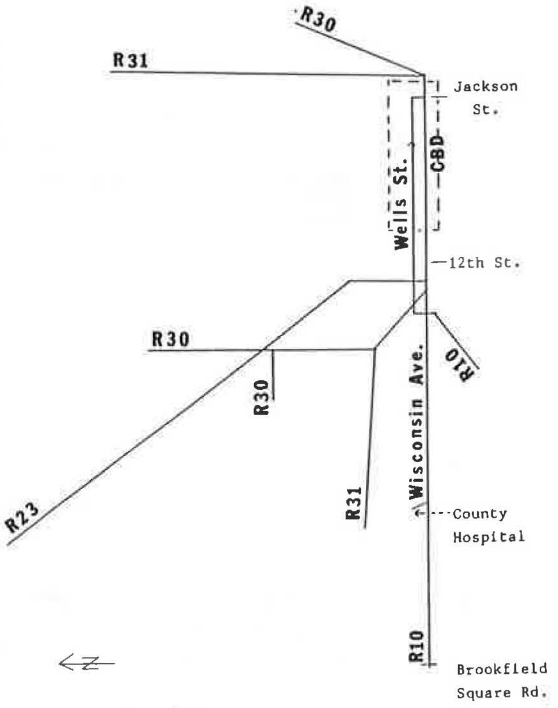

FIGURE 1 Route location map.

DATA COLLECTION METHOD

The MCTS defined the time points as the bus leaving times. Toward this end, the procedures described next were used to collect the data.

At intermediate points, the following standards were used: (1) if buses did not stop, the times when the front doors of buses just passed the stop post were recorded; (2) if buses stopped at the bus stop and the traffic signal at the intersection was green, then the times when buses started to move were recorded; and (3) if buses stopped at the bus stop and the intersection traffic signal was red, then the times when buses started to move after the signal turned green were recorded.

At end points of the route, the arriving times were recorded when the bus doors were opened.

Before and after a data collection session, the time of the digital watch used was checked with the central phone time. This phone time is used by Milwaukee County Bus Transit drivers to meet the schedules. The correct published schedules used by the drivers were obtained from the MCTS. The recorded or observed times were subtracted from the scheduled times. The differences were recorded in seconds. A negative time means the bus was early, and a positive time indicates the bus was late.

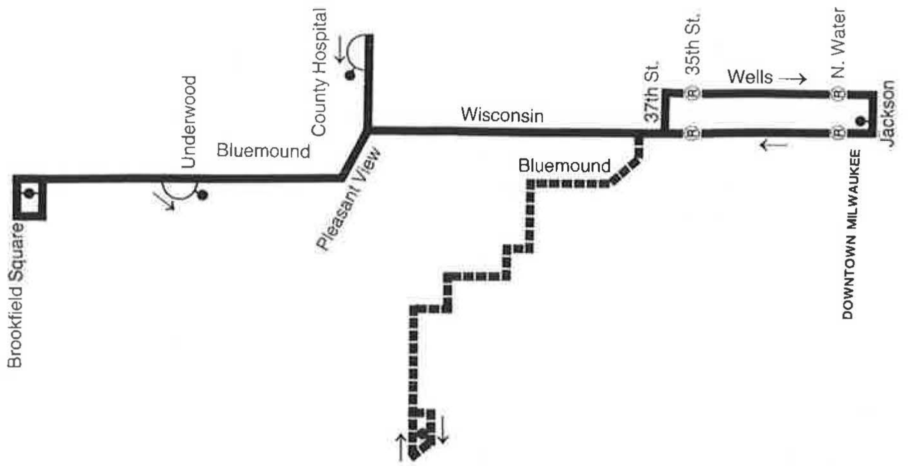

FIGURE 2 Time points and route destinations for Route 10.

Milwaukee's "window" of on-time is from −60 to +180 seconds plus 15 seconds of rounding to −75 to +195 seconds. Consequently, all data within this range should be considered on time.

Data were collected for peak and midday periods. Morning peak extends from 7:00 a.m. to 10:00 a.m., while evening peak is from 3:00 p.m. to 6:00 p.m. Midday data were recorded between 11:00 a.m. and 1:00 p.m. All data were recorded on weekdays.

ANALYSIS OF ON-TIME PERFORMANCE

Frequency and other statistics were used first to analyze the data. Table 3 shows the statistics of each route and of all routes combined. Buses were recorded as early as −522 seconds (−8.7 minutes) and as late as 693 seconds (11.55 minutes).

Figure 3 shows the relationship between the ranges of headways and their related average arriving times. The shortest range of headways (0–5 minutes) has the highest mean (79 seconds) of adjusted arrival times. Then the mean decreases as the headway increases. The mean drops to 18 seconds when the headway ranges from 11 to 15 minutes. It increases sharply, however, when the headway ranges from 16 to 20 minutes. But then, it drops again when the headway is equal 21 minutes or more.

An analysis was also performed to compare the arriving times at different points along Route 10 (see Table 4). The result shows that, on average, eastbound buses arrived much earlier than westbound buses. However, the east end of the route for this part of the analysis is in the downtown area. Table 4 also shows that while buses arrived earlier than the scheduled times at end points, they arrived later than the scheduled times at the 12th Street-Wisconsin Avenue stop, near the peak load.

There are many reasons that buses often arrive earlier than the scheduled times. Traffic may be less congested in areas away from the central business district. And the distance between stops may be longer. These factors enable bus drivers to speed up once they know they are late. In addition, once buses move farther away from a peak load area, fewer pas-

TABLE 3 STATISTICS OF EACH ROUTE AND OF ALL ROUTES COMBINED (ADJUSTED ARRIVAL TIMES)

	Value					Sample
Route	Lowest (second)	Highest (second)	Mean	Median	Std.Dev.	Size
10	-244	545	34	22	130	183
23	-288	598	57	52	151	204
30	-522	617	49	37	134	268
31	-180	693	45	27	149	137
All	-522	693	47	33	140	792

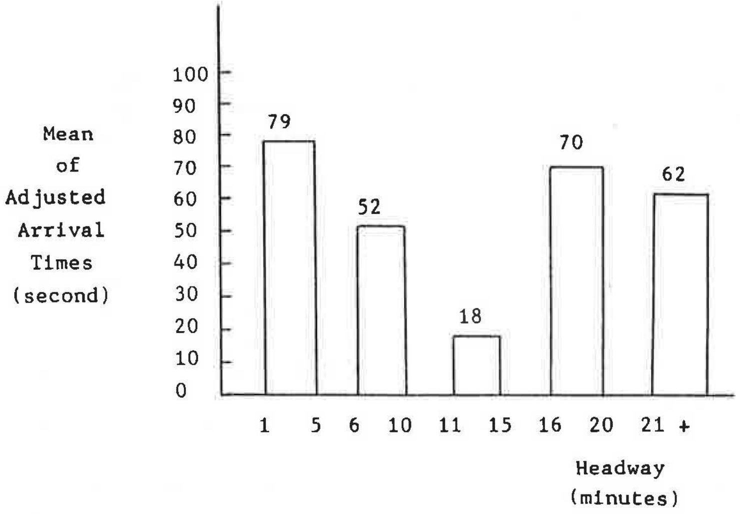

FIGURE 3 Adjusted arrival times as a function of headways.

sengers board the buses. Also, there is a greater pressure on the drivers to be there on time and make the buses available for the next run. One incentive to arrive earlier at the end points is the extra time drivers can have to drink a cup of coffee or to read a newspaper.

The respective performances of the eastbound and westbound buses were compared as shown in Table 5. The means of each peak period and midday period of westbound buses are higher than the ones of eastbound buses. This means that, on average, the westbound passengers waited longer than the eastbound passengers.

The data also show that while buses in morning and evening peaks arrived later than the scheduled times, midday buses arrived earlier than the scheduled times (see Table 6). This could be due to less congested traffic and a smaller volume of passengers in midday.

TABLE 4 COMPARISON FOR DIFFERENT POINTS (ROUTE 10 ONLY)

	County Hospital	12th street	Jackson-Wisconsin
	WB (second)	EB & WB (second)	EB (second)
Mean	-17	34	-63
Std.Dev.	104	130	193

WB - Westbound

EB - Eastbound

TABLE 5 WESTBOUND AND EASTBOUND COMPARISON OF ADJUSTED ARRIVAL TIMES (ALL ROUTES AT 12TH STREET)

	Eastbound (second)			Westbound (second)		
	M.Peak	Midday	E.Peak	M.Peak	Midday	E.Peak
Mean	33	-1	41	71	39	78
Std.Dev.	156	123	155	128	142	118

TABLE 6 COMPARISON OF PEAKS AND MIDDAY OF ADJUSTED ARRIVAL TIMES (ALL ROUTES AT 12TH STREET)

	M.Peak (second)	Midday (second)	E.Peak (second)
Mean	51	-71	60
Std.Dev.	144	134	139

DISTRIBUTION OF ON-TIME PERFORMANCE

Finally, an analysis was made to find the distribution of on-time performance. A USPRP IMSL subroutine was used to find the probability distribution of on-time performance (*7*). This program was used for the purpose of initial screening. The results show that the distribution follows closely the normal distribution from the left tail (early arrivals) only up to a certain point before the right tail. Consequently, this distribution does not appear to fit a normal distribution. Because rarely are buses extremely early but sometimes are extremely late, an appropriate distribution would logically be one with a long right (positive) tail and a short left (negative) tail. Examination of standard continuous distributions indicated that under certain conditions, either a gamma or a log normal distribution fits this description. Since the range of both of these distributions is from zero to infinity, the data were transformed so that the smallest value of the data became zero.

To see whether the data could be represented by either distribution, the Kolmogorov-Smirnov test was performed. One constraint of the Kolmogorov-Smirnov test is that the population parameters cannot be estimated from the sample. Consequently, for this analysis, the odd-numbered observations were used to estimate the parameters, and the even-numbered observations were used for fitting the distribution. This is a standard procedure (*8*).

To perform this test, the largest vertical difference between the theoretical cumulative probability distribution and the actual cumulative probability distribution should be found. This value is then compared to the Kolmogorov-Smirnov Z value, which for an alpha of 0.01 equals $(1.63/n^{0.5})$ if n, the sample size, is greater than 35. These data have a sample size of 396, yielding a Z value of 0.081. For a value greater than the Z value, the null hypothesis that the data are gamma or log normally distributed can be rejected.

The vertical differences were computed between the cumulative probability of the theoretical distributions and the cumulative probability of the actual data (see Table 7). The largest difference for the log normal distribution is 0.0829, indicating that the data are not log normally distributed. However, the largest difference for the gamma distribution is 0.0704. Therefore, the null hypothesis cannot be rejected. The distribution of adjusted bus arrival times appears to be best represented by a gamma distribution.

The theoretical formula of a gamma distribution density function is expressed as follows:

$$P(x) = \frac{\beta^{\alpha} x^{\alpha-1}}{\Gamma(\alpha)} e^{-\beta x} \quad x > 0 \tag{2}$$

TABLE 7 THEORETICAL AND OBSERVED CUMULATIVE PROBABILITY DISTRIBUTIONS

Adjusted Arrival Time (seconds)	Observed	Gamma		Lognormal	
		Theoretical	Difference	Theoretical	Difference
242	0.0050	0.0015	0.0035	0.0003	0.0047
302	0.0100	0.0126	-0.0126	0.0068	0.0032
402	0.0680	0.1116	-0.0436	0.1020	-0.0340
450	0.1920	0.2148	-0.0228	0.2148	-0.0228
500	0.3280	0.3535	-0.0255	0.3632	-0.0352
551	0.4370	0.5074	-0.0704*	0.5199	-0.0829*
601	0.6340	0.6489	-0.0149	0.6628	-0.0288
650	0.7320	0.7642	-0.0322	0.7734	-0.0414
700	0.8230	0.8525	-0.0295	0.8554	-0.0324
798	0.9240	0.9503	-0.0263	0.9463	-0.0223
900	0.9700	0.9869	-0.0169	0.9830	-0.0130
1002	0.9920	0.9971	-0.0051	0.9949	-0.0029
1201	1.0000	0.9999	-0.0001	0.9996	-0.0004

*Highest difference

with

$$\bar{x} = \frac{\alpha}{\beta} \tag{3a}$$

$$s^2 = \frac{\alpha}{\beta^2} \tag{3b}$$

and

$$\Gamma(\alpha) = \int_0^\infty x^{\alpha-1}e^{-x}dx \tag{3c}$$

where

α,β = parameters of the gamma distribution,
$\bar{x}$ = mean of the sample,
s^2 = variance of the sample,
x = a random variable, and
Γ = the gamma function.

A computer program including the preceding formulas was used to generate the gamma distribution function. The values of alpha and beta used in this program were calculated by using Equations 3a and 3b, as follows:

$$\bar{x} = 559.3$$

$$s^2 = 18125.8$$

$$\beta = \frac{\bar{x}}{s_2} = \frac{559.3}{18125.8} = 0.0309$$

$$\alpha = s^2\beta^2 = 18125.8 \times (0.0309)^2 = 17.258$$

After substituting the values of alpha and beta into Equation 2, the final equation becomes:

$$P(x) = 1.97 \times 10^{-40} (x + c)^{16.258} e^{-0.0309(x+c)} \tag{4}$$

where

X = bus arrival time and
c = constant, the earliest bus arrival time (−522 in this situation).

The theoretical gamma cumulative distribution function and the distribution of observed data were plotted in Figure 4. The probability of bus arrival at a bus stop can then be predicted by using Equation 4.

COMPARISONS WITH PREVIOUS STUDIES

Because past studies have used different approaches or methods, an exact comparison is difficult. Each of these studies showed different results.

Turnquist (*2*) suggested that the distribution of bus arrival times at a point along a route is log normal (see Figure 5a). Because a logarithm is not defined for zero or negative numbers, a transformation also needs to be applied to this function.

Talley and Becker (*6*) proposed that the exponential probability distribution (see Figure 5b) be used to compute the probability that buses will be more than x minutes early and more than y minutes late.

In the present study, the bus arrival times tended to follow the gamma distribution (see Figure 5c), which also requires a transformation. The existence of a shorter left tail than right tail of the gamma distribution makes it appropriate for this situation. The left tail indicates that there are some rather extreme values. This is often the case in day-to-day bus operations; some buses arrive quite early. The shorter left tail is expected because earliness, represented by the left tail, can be controlled. When drivers feel that they are early, they can slow down or wait for a time at bus stops. If they are late, however, the only thing they can do is speed up a little or, maybe, not stop at certain points along the route. Lateness can be caused by many factors that bus operators cannot control. One of them is bad traffic conditions. Because of these uncontrolled factors, some buses may arrive extremely late. These extremely late arrivals are represented by the long right tail of this gamma distribution.

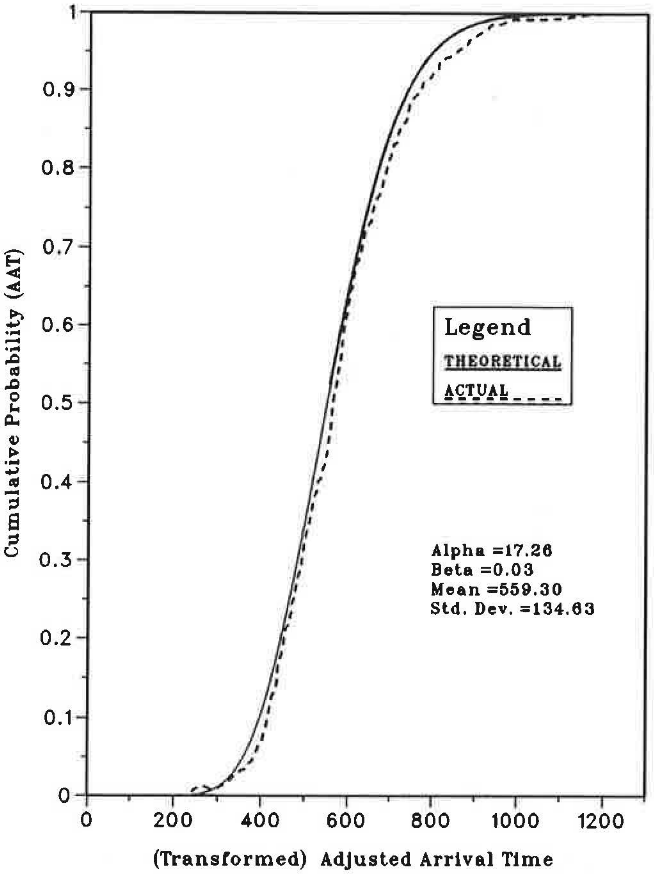

FIGURE 4 Cumulative gamma distribution of adjusted arrival times.

CONCLUSIONS

On-time performance can be used to improve operating efficiency (better headway planning) and to increase revenue (attract more people to ride buses). In addition, passenger waiting times can be reduced. In general, on-time performance can significantly improve the public perception of the transit system.

The term *adjusted arrival time* was used for on-time performance. An analysis was made to obtain the statistics of the adjusted arrival times. The adjusted arrival times in terms

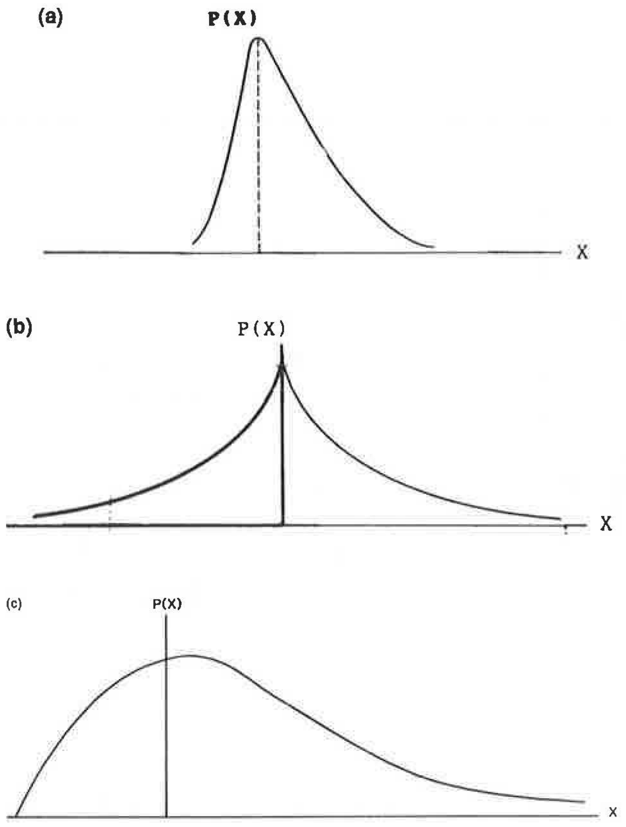

FIGURE 5 (a) Log normal distribution, (b) exponential distribution, and (c) gamma distribution.

of headway, direction, and time of day were studied. An analysis was performed to study the distribution of adjusted arrival times.

The results of the study showed that adjusted bus arrival times follow a gamma distribution. This distribution can be used to (1) measure the on-time performance using a significantly smaller sample size, (2) estimate the probability of a bus being on time, and (3) model passenger waiting times, passenger arrivals, and on-time performance. This finding differs from the ones that had been proposed in the past.

In addition, a theory was proposed that adjusted arrival times are functions of the distance along a route, the location of peak load point, and the headway. Buses in the morning and evening peaks tend to arrive late. However, the midday buses tend to arrive early.

More research is needed to improve bus transit on-time performance and to study the effect of on-time performance on ridership and on reputation of bus operators. To confirm that the gamma distribution fits bus arrival times, more data from other cities are needed. A log normal distribution should also be considered because of the similarities between the two distributions. More data are also needed to explore the theories of bus arrival times as a function of distance along a route and bus headway and why they occur as they do.

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Planning Guidelines for Transitway Access

Kevin A. Haboian

With the problems inherent in preserving freedom of movement in rapidly developing urban areas, many agencies are advising the use of transitway facilities to provide exclusive guideways for buses, carpool, and vanpools in congested freeway corridors. Vehicles wishing to gain access to the earlier high occupancy vehicle (HOV) facilities were required to weave across heavily traveled, general-purpose freeway lanes. However, in recent years, the need for direct access to these facilities has been recognized. For example, in Orange County, California, a system of transitways 19.4 miles long is being proposed for the major freeway corridors. With this priority system, a network of direct access locations is being linked to the surrounding arterial system. In designing this network, a set of planning guidelines was developed to select the best individual access locations to be included. This paper describes these planning guidelines, involving growth trends, infrastructure issues, and design considerations, which should be useful to transportation planners and engineers in analyzing transitway access locations.

As urban areas become increasingly more populated, transportation planners and engineers face the challenge of preserving ease of movement in a highway system that is often near or over capacity. Transitway facilities for buses, carpools and vanpools, are becoming popular as an approach that can enhance the people-moving capacity of major travel corridors. The Orange County Transit District (OCTD) is developing a 19.4 mile bidirectional transitway system within its major freeway corridors with direct access from the arterial system (Figure 1). This approach is unique in that it represents a network of transitway access locations which will connect with the major activity centers and the local arterial system. Other transitway facilities across the country (e.g., Seattle, Miami, Los Angeles, and Washington D.C.) provide isolated access locations with an adjacent arterial or park-and-ride lot, but access is provided mainly from the general-purpose freeway lanes.

OCTD is investigating development of a network of direct access locations for three reasons:

1. Transitways assume a high-speed level of service during peak commuting periods and offer travel time savings as an incentive. Direct access ramps ensure this time savings by eliminating the need for vehicles to weave across heavily traveled freeway lanes when exiting the facility. Without these direct access locations, vehicles must exit the facility into the highly congested freeway lanes, typical of central Orange County, which may negate the travel time benefit.
2. The implementation of a commuter lane on SR 55 (see Figure 1) resulted in many complaints and safety concerns from commuters. The perception was that many unnecessary accidents were occurring on the freeway as a result of vehicles weaving in and out of the high-occupancy facility. Direct access ramps provide safer traffic operation by precluding these weaving movements, resulting in fewer accidents and responding to the public's safety concerns.
3. A preliminary cost effectiveness analysis was performed to find out whether direct access ramps would be feasible. Preliminary capital costs, demand usage, and travel time savings estimates were used to determine whether the potential benefit of a direct access ramp exceeded the dangers of not doing so. Results of this analysis indicated that direct access ramps were practicable at several locations.

The reasons discussed above led OCTD to engage in more detailed planning to incorporate a transitway access network.

The questions that faced the transportation planners and engineers in the initial stages of the design process in Orange County were numerous. What objectives should be considered in developing a transitway access network? What were the factors that make one potential location better suited for transitway access than another? Clearly some form of planning approach or guidelines were needed to respond to these questions. This paper describes planning guidelines that were developed and applied in Orange County to describe the best transitway access network. These guidelines were grouped into three general categories—growth trends, infrastructure issues, and design considerations.

GROWTH TRENDS

An absolute requirement for establishing a transitway access network is understanding the growth trends of the areas to be served. The design team is responsible for this understanding, but local jurisdictions are responsible for coordinating their land use activities with the proposed transitway system to protect and enhance system benefits. Specifically, understanding encompasses identifying the major activity centers to determine whether their projected growth supports the need for transitway access (*1*). Attention must also focus on adjacent land uses to ascertain whether the current and proposed development patterns will ensure mobility for people commuting to the major activity centers.

Major Activity Centers

An activity center is usually defined as an area of intense, increasing development of office and commercial activities (*2*). In Orange County the major activity centers were identified by the geographical area served, employment activity,

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Parsons Brinckerhoff Quade & Douglas, Inc., 505 South Main Street, Suite 900, Orange, Calif. 92668.

FIGURE 1 Transitway and commuter lane system.

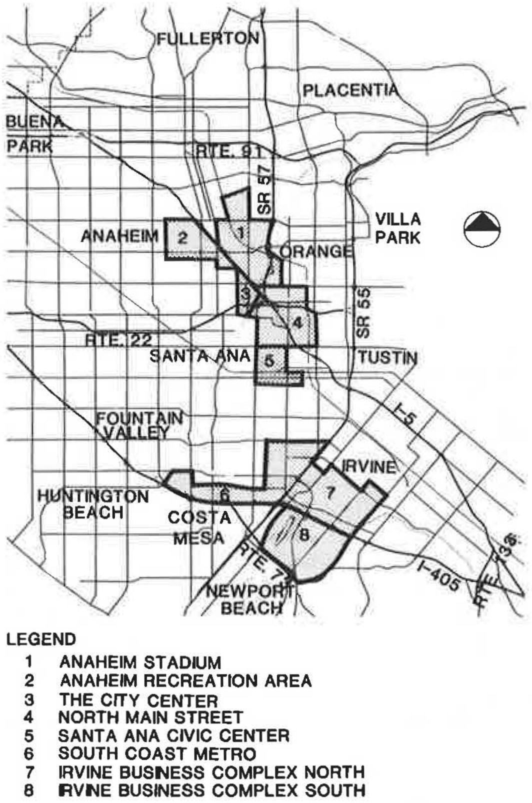

FIGURE 2 Major Orange County activity centers.

and changes in development policies. Eight activity centers, shown in Figure 2, are the major destinations for employees in Orange County, and provide the greatest potential for carpool and transit usage. These eight centers, each within one mile of the major freeway corridors in the area, all depend on freeways for their primary access. Moreover, all eight centers contain major proposals for intensifying development of either office complexes, industrial uses, or regional shopping centers. Linking these activity centers to the transitway by a network of transitway access locations promotes the principal objective of a transitway program: to increase mobility while saving travel time. After the major activity centers have been identified, employment projections are needed to estimate the transitway use expected for each activity center and for use in designing the most responsive transitway to serve each center. The design team can then determine whether the employment projections justify transitway access consideration.

Based on plans adopted for each activity center, forecasts of jobs for each center were estimated and are shown in Table 1. The employment forecasts for these centers account for more than 25 percent of all Orange County employment throughout the projection period. The employment estimate for each activity center in the year 2010 ranged from 16,700

TABLE 1 ORANGE COUNTY MAJOR ACTIVITY CENTERS: CITY STAFF GENERATED EMPLOYMENT PROJECTIONS

	Projected Employment		
Activity Center	**1985**	**2000**	**2010**
Anaheim Stadium	34,192	71,504	95,640
Anaheim Recreation Area	25,089	29,114	31,788
The City Center	12,167	15,934	16,700
North Main Street	17,960	24,978	29,691
Santa Ana Civic Center	23,876	26,759	30,109
South Coast Metro	40,048	60,323	67,053
Irvine Business Complex North	40,000	72,384	75,306
Irvine Business Complex South	46,792	55,240	59,776
Total	240,124	356,236	406,063
Total Orange County	1,130,700	1,436,600	1,570,500
Percent Activity Center of Total Orange County	21%	25%	26%

to 95,640 with total employment for the eight centers estimated at more than 406,000. These employment forecasts were then used to develop transit and HOV usage estimates for the year 2010 (Table 2).

Two sets of HOV estimates were produced for the forecast year: one based on the assumption that transitways would be open to vehicles with two or more persons, and a second that assumes transitways would be restricted to vehicles with three or more persons. The transitway system is projected to carry approximately 3,000 HOV trips in the morning peak hour, using an eligibility of three or more persons per vehicle. A much higher estimate of approximately 11,000 HOVs results if two-person carpools are allowed to use the transitways. Express transit service on transitways is projected to carry 22,100 daily riders in the year 2010. Approximately 140 buses would be needed during the peak hour. Maximum forecasted demand for any one segment is 6,100 directional transit and HOV person trips in the morning peak hour, equivalent to the capacity of the number of person-trips that can be accommodated by three general-purpose freeway lanes. The design team reasoned that employment and transitway usage projections justified consideration of transitway access locations with the activity centers.

Adjacent Land Use

Establishing a transitway system together with a network of access locations represents a major public capital investment, but is only part of the solution for ensuring personal mobility for employees and visitors to the major activity centers. The characteristics of adjacent land uses also play an important role. During the planning stage of a transitway access network, the design team must consider the nature of current land use when recommending individual access locations. These considerations can range from the type of development near the proposed access locations, to the feasibility of including the access location in the arterial system. However, it is the responsibility of the local jurisdictions to coordinate their future land use activities to take full advantage of the benefits of the access location. Specific local activities which can offer benefits to, as well as receive benefits from, a transitway access location are as follows:

1. Focusing new land use developments and public street improvements where they can offer best access to the transitway and ensure convenient, safe travel between the transitway access location and individual employment sites.
2. Promoting programs that support rideshare modes in current developments and requiring rideshare programs as a condition of development for new land use proposals.
3. Providing HOV preferential treatment facilities between the transitway access location and the activity centers. Preferential treatment can include bus turnouts, parking areas reserved for HOVs, signal preemption, improved signs, or even exclusive HOV lanes leading from the transitway ramps to employment sites.

INFRASTRUCTURE ISSUES

Development of a transitway and a network of access locations in an urban setting will undeniably require a certain amount of reconstruction of the highway system. Selecting the access locations to reduce reconstruction to a minimum, to serve the major activity centers in fitting style, and satisfy all the agencies involved, is of the utmost importance in the planning stage. Arterial and freeway impacts, interagency coordination, and the ability to incorporate preferential treatment in the future, all involve key issues that must be addressed to successfully develop a transitway access network.

Arterial and Freeway Impacts

The principal objective of a direct access location is to connect the transitway facility, usually located within the freeway median, with the local arterial system. When selecting a location for direct access, the design team must assess the potential impact of the transitway ramp on both the local street and freeway facilities. For instance, the dimensions, orientation, or configuration of a local arterial may be ideally suited for a direct access ramp, but the freeway impacts associated with the ramp connection to the transitway may be less than the best. Such freeway impacts could include extensive right-of-way acquisition caused by having to widen the freeway cross-section, or impaired HOV access to other freeways. Consequently, the reconstruction and traffic flow impacts associated with arterial and freeway connection must be analyzed simultaneously, because the transitway ramp links each facility. To reduce arterial and freeway interchange impacts when selecting potential transitway access points, three factors must be considered:

1. Access points near freeway-to-freeway interchanges should be not be constructed because there would be insufficient distance to allow HOVs emerging from the transitway ramps access to each freeway. Moreover, the cost of building new

TABLE 2 TRANSITWAY DEMAND ESTIMATES FOR YEAR 2010

	High Occupancy Vehicles HOV's Restricted to:		**Transit**
	2 Persons or More	**3 Persons or More**	**Public and Private Service Combined**
SR 57/I-5/SR 55 TRANSITWAY			
o Daily Person Trips	123,600	52,700	22,100
o AM Peak Hour Vehicles			
- Total on Facilities	11,000	3,000	140 buses
- At Maximum Location in one direction	3,700	1,400	50 buses

facilities over or around freeway interchange structures would be high, possibly negating the feasibility of the project.

2. Care should be taken to avoid arterial locations where general-purpose freeway access is currently provided or proposed. Incorporating transitway ramps at these locations will usually require relocating or realigning the general-purpose ramps to accommodate the additional access. Also, the traffic distribution to accommodate vehicles entering the transitway and freeway facilities may require installing additional signals, resulting in lower-level service to HOV and general-purpose traffic flow.

3. Traditionally, there is lower demand with HOV ramps compared to general-purpose freeway ramps. In Orange County, the average a.m. peak-hour volume projected for each transitway access ramp is just under 500 HOVs, which corresponds to approximately 15 percent of the total demand at the HOV/local street intersection (*3*). This lower demand indicates that, ideally, transitway access locations should be built at collector or secondary arterials. These facilities traditionally have lower volumes, do not contain general-purpose freeway ramps, and could provide access to primary arterials by way of current signalized intersections.

Interagency Coordination

Coordinating with all agencies potentially affected by a transitway access ramp, and as well as those who may potentially benefit from it, is usually the critical factor in gaining acceptance of the access location. Some agencies need to be contacted early in the planning process to ascertain future plans for their transportation facilities. Discussion of these plans will usually arise during regularly scheduled meetings. Other agencies should be informed of the proposed transitway access location because its construction may help future planned city expansion or, in the case of a developer, a future project. It is important to realize that often there is no formal procedure to aid in this process; planning is usually an iterative process in which a consensus may be reached after several meetings. The consensus may incorporate a project that includes improvements desired by several agencies interested in funding or co-sponsoring the HOV access improvements with other general-purpose traffic improvements.

In Orange County, such a consensus was reached with three separate entities: OCTD, California Department of Transportation (Caltrans), and the City of Santa Ana. Caltrans was developing freeway (I-5) widening plans and the City of Santa Ana was planning local arterial and freeway access improvements when OCTD, responsible for the transitway program from its inception, organized several meetings with these agencies. The meetings resulted in a consensus that incorporated the proposed transitway within Caltrans I-5 widening plans and provided direct access between the transitway and local street system at two locations in Santa Ana.

Orange County transitway planning activities also provided an example as to how a transitway access location can act as a catalyst in future city/developer plans. The SR 55 freeway essentially forms a city boundary separating the cities of Santa Ana and Irvine. A transitway is proposed along this facility, with arterial access ramps envisioned at several locations. One arterial access alternative, Alton Avenue, is a proposed freeway overcrossing which would connect the arterial on each side of SR 55, thereby joining two rapidly expanding cities. This proposed overcrossing could provide access to the planned office and industrial developments in both Santa Ana and Irvine. Developers planning projects in the vicinity of Alton Avenue would support the idea, since the planned access would facilitate city approval of their projects. Consequently, rather than having to persuade the cities and developers of the merits of the proposal of transitway access, these very same entities begin advocating its implementation to the community and surrounding cities. This support, in turn, aids in developing the transitway access network. It is important to realize that no one specific reason or formal process can obtain such an outcome. Support will arise during planning activities in which close coordination, frequent meetings, and understanding of differing viewpoints transpire with the entities involved.

Extending HOV Preferential Treatment To Local Streets

One of the key benefits of developing a transitway system is saving travel time and it has been estimated that travel time savings of at least one minute per mile is required for people to shift modes from cars to buses or carpools. After users leave the transitway, it is desirable to extend travel time savings to the local street system where feasible. Thus, when selecting transitway access locations, attention should also be directed to the arterial system to ensure that future arterial HOV improvements can provide the same saving of travel time.

Arterial HOV improvements can be separated into both high capital and low capital cost treatments. High capital treatments involve exclusive use of lanes and streets, and consist of concurrent flow lanes, contraflow lanes, median/center lane facilities, and reserved roadway facilities. Because of the right-of-way requirements necessary to implement high capital treatments, studies to determine whether implementation is feasible should be conducted early in transitway planning activities. Low capital measures usually involve minor alterations to streets and modifying the operation of traffic control devices. Such improvements as pavement striping, signal progression and signal preemption, bus turnouts, and improved signs can be made as needed after the transitway system begins operation.

DESIGN CONSIDERATIONS

In establishing a network of transitway access locations, it is important to realize that the design of each individual access point will be site-specific. The special characteristics of each site will make it difficult to ascertain whether one potential access location is better than another based on design criteria used in the planning stage. However, the following sections describe several general design considerations which can be used to develop feasible transitway access locations.

Minimize Right-of-Way Acquisition

Care should be taken to use freeway right-of-way where available (*4*). This not only includes right-of-way at the perimeter of each direction of travel, but within the median as well. Right-of-way acquisition can be publicly unpopular as well as environmentally sensitive, and may require significant mitigation measures (soundwalls, etc.). Often in an urban area, there may not be any available right-of-way and acquisition is unavoidable. Such a situation occurred in Orange County and the amount of right-of-way necessary to construct a transitway access ramp varied depending on the characteristics of each site. In an attempt to compare the right-of-way impact associated with each proposed access location, acquisitions were separated into minor and major categories. Minor right-of-way takes did not affect any present or proposed buildings and were usually small acquisitions of less than 20 linear feet beyond the right-of-way boundary. Major right-of-way takes typically affected present or proposed buildings and involved obtaining large parcels of land. These categories allowed the design team to compare the right-of-way acquisition impact to select the best access locations.

Avoid Extensive and Complex Designs

Steep grades, insufficient right-of-way, overcrossings at existing railroads, freeway interchanges, general-purpose ramps, and limited weaving areas can all cause major structural modifications and complex access designs, and should therefore be avoided when possible. Preliminary studies in Orange County indicate that access locations where the transitway can be connected to an overpassing arterial street can be cost-effective and cause few impacts. With this configuration, shown in Figure 3, through transitway traffic continues to operate on the transitway at freeway grade level. Traffic desiring to enter or leave the transitway uses a ramp that connects the transitway to the grade-separated street.

Environmental Impacts

The environmental impact of building new facilities is always a major issue in the local community. For the design process in Orange County, an attempt was made to determine the environmental impacts associated with each potential access location. This action was not intended to substitute for an Alternatives Analysis or Environmental Impact Statement, but rather to gain some idea of the impacts that could be expected with each transitway access option. These impacts, rated as none, minimal, and significant, were a subjective estimation of noise levels to adjacent property, displacement of sensitive parcels, and facility aesthetics (i.e., large amounts of structure required for an access location would be rated as significant).

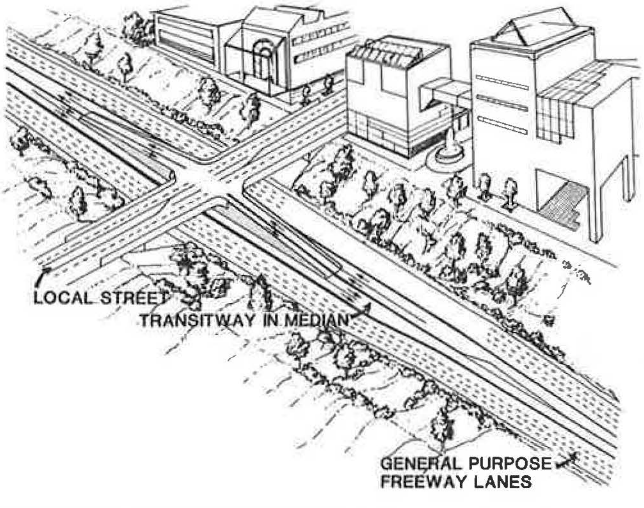

FIGURE 3 Drop ramps in median of two-way transitway.

Costs

The cost of building individual access locations, for the most part, will determine the feasibility incorporating that location into the transitway system. If the aforementioned issues concerning right-of-way acquisition, complex designs, and environmental impacts are followed, the cost of building a transitway access location should not be unreasonable. In Orange County, the cost of constructing a transitway access ramp similar to that shown in Figure 3.3 ranged from $3.3 million to $6.2 million.

USING THE PLANNING GUIDELINES: METHODOLOGY USED IN ORANGE COUNTY

There are many factors to consider in choosing the best place to incorporate an access point into a transitway access network. The planning guidelines presented in this paper cite specific issues to consider in developing such a network. On the basis of the Orange County experience, there is a procedure for identifying the best possible transitway access locations.

The first task was to identify the possible access points to the activity centers in relation to the proposed transitway system. The factors considered in identifying potential access points included the following:

1. Understanding present and future activity centers.
2. Nearness of the activity center to the potential access location.
3. Reducing the impact to existing interchanges and street systems.
4. Discussions with Caltran's staff to ensure that any proposed access would not conflict with future freeway modifications.

A complete list of all the potential access points along the proposed transitway alignment was identified using these four factors.

The list was then screened to obtain the most effective system of ramps which would support the transitway system. This was accomplished by using negative screening criteria analysis. If an access point met any of these criteria, it usually was not considered for further analysis. However, certain access points met one of the negative criteria and yet were considered further because of ease of construction or proximity to activity centers. The fact that an access location was not analyzed further did not preclude it from future consideration. The purpose of the Orange County conceptual design was to identify potential feasible locations for transitway ramp connections. Final approval of access locations will be based on a detailed Alternatives Analysis. The negative screening criteria used in the analysis were as follows:

1. Transitway demand related to activity center.
2. Arterial and interchange traffic impacts.
3. Extensive and complex design problems.
4. Proximity to freeway-to-freeway interchanges.

The first criterion was established because the transitway is primarily set up to serve the work trip and access points must be situated so that vehicles using the transitway ramp can gain access to the activity centers. Locations where the transitway access point would not efficiently serve the activity center were considered undesirable. The remaining three criteria were considered to be undesirable for the reasons stated earlier.

Table 3 shows the potential activity center access points considered and the evaluation of these access points using the negative screening criteria. With this screening process, 15 access points were identified for more detailed evaluation.

At this juncture, alternative conceptual designs were developed for each access location selected. For certain locations, several alternative configurations were developed, while the design constraints of other potential access points made only one configuration feasible. To ascertain the access locations best suited for inclusion in the transitway access network, the design impacts were assessed in light of the design issues previously defined. This assessment gives a general estimation of each access location's impact in terms of cost, right-of-way take, traffic flow on the transitway ramp and surrounding local arterials, and environmental concerns. Costs were separated into three categories, less than \$10 million, between \$10 and \$20 million, and greater than \$20 million, while the other design issues were rated subjectively. Table 4 presents this assessment for several potential transitway access locations.

Based on the foregoing considerations and implementation impacts, nine access locations shown schematically in Figure 4, were considered to be reasonable options for incorporation into a transitway access network. It should be noted that even though this methodology is relatively simplistic, it took approximately six months to obtain this outcome. If the plan-

TABLE 3 SCREENING EVALUATION OF POTENTIAL TRANSITWAY ACCESS POINTS

Route	Access Points Considered	Evaluation[1]
57	Ball Road	(1) (2)
57	Cerritos Avenue	*
57	Katella Avenue	(2)
57/River	Anaheim Stadium	*
57	Orangewood Avenue	(2)*
57	Chapman Avenue	(2) (4)
57/22/River	Metropolitan-Hospital Loop	(4)
57	LaVeta Avenue	(3)*
5	Chapman Avenue	(3) (4)
5	State College/The City Drive	(3) (4)*
5	Orangewood Avenue	(3)
5	Pacifico Avenue	*
5	Katella Avenue	(2) (3)
5	Flower Street	(4)
5	Broadway/Owens Drive	(3)*
5	Main Street (Santa Ana)	*
5	17th Street	(2)
5	Lincoln Avenue	(1) (3)
5	Grand Avenue	*
5	4th Street	(1)*
5	1st Street	(1) (2) (4)
5	Main Street (Tustin)	(1) (4)
55	McFadden Avenue	(1) (4)
55	Edinger Avenue	(1)
55	Warner Avenue	(1)*
55	Dyer Road	(2)
55	Alton Avenue	*
55	MacArthur Boulevard	(2)
55	Sunflower Avenue	*
55	Main Street (Irvine)	(4)
405	Bristol Street	(2)
405	Bear Street	*
405	Redhill Avenue	(4)
405	MacArthur Boulevard	(2)
405	Von Karman Avenue	*
405	Jamboree Boulevard	(2)

[1] If access point meets anyone of the negative screening criteria listed below, it usually was not considered for further analysis.

(1) Transitway demand related to the activity center
(2) Arterial and interchange traffic impacts
(3) Extensive and complex design problems
(4) Proximity to freeway-to-freeway interchanges

*Access points considered for further analysis.

TABLE 4 TRANSITWAY ACCESS LOCATION DESIGN ISSUES ASSESSMENT

Location	Cost	Right-of-Way Take	Traffic	Environment
Grand Elevated Connection To Santa Ana Boulevard	$$$	Major	Good	Significant
Grand Tunnel Connection To Santa Ana Boulevard	$$	Minor	Good	Minimal
Broadway/Owens	$$	Major	Good	Significant
Main	$	Major	Fair	None
Anaheim Stadium	$$$	Major	Good	Significant
Cerritos	$$	Minor	Good	None
Orangewood	$$	Minor	Poor	Minimal

ning guidelines for transitway access had not been developed, it would have taken considerably longer to obtain the conceptual transitway access network.

CONCLUSION

The proposed transitway within Orange County's major freeway corridors exemplifies the type of HOV facility that can preserve mobility in rapidly developing urban areas. Reduced travel time is the key incentive offered by these facilities and obtaining the maximum time savings through good accessibility is essential. In response, Orange County is planning a network of direct access locations with the surrounding arterial system. The many factors and objectives influencing selection of the best possible access network resulted in the adoption of planning guidelines for use in evaluating growth trends, infrastructure issues, and design considerations. These guidelines factored critical characteristics into the selection of ramp locations during the transitway access planning process.

Although the Orange County experience can be considered unique to the circumstances of planning a transitway access network, several observations from this experience can apply to other jurisdictions. Employment forecasts are needed for the major activity centers to be served by the transitway facility because these estimates will be used to project usage of the proposed access locations. Local jurisdictions must be kept abreast of the transitway planning process so that their future land use activities will achieve maximum benefit from the planned access location. Moreover, transitway access designs should be as simple as possible to reduce costs and avoid public unpopularity resulting from right-of-way acquisitions of buildings and environmentally sensitive areas. Perhaps most important, the responsible agency must work closely with all agencies that may benefit from, or be affected by, a proposed transitway access ramp. Such coordination may result in a consensus by agencies with an interest in funding a transitway access location with other general-purpose traffic improvements.

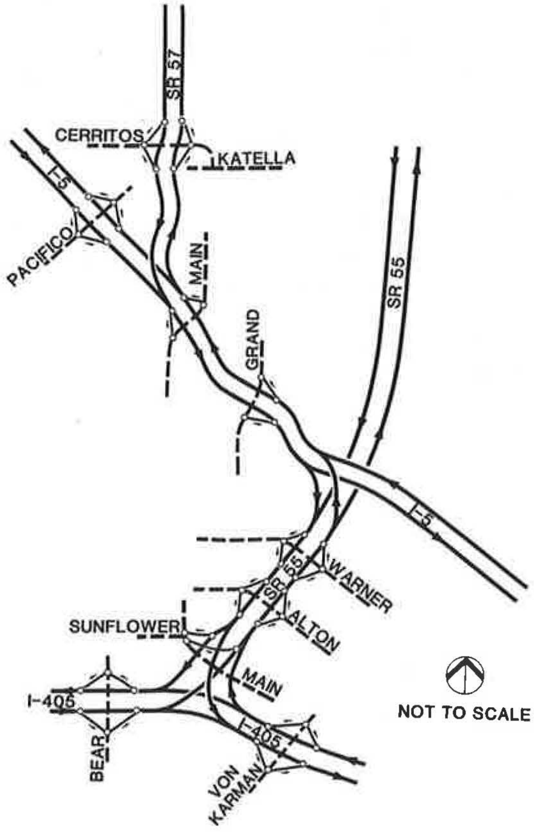

FIGURE 4 Transitway access locations.

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Assessing the Accuracy of Driver Passenger Counts: The Experience of AC Transit

David Koffman and Diane Nygaard

Passenger counts by bus drivers are subject to unknown errors. A sample of regular counts by AC Transit drivers, using electronic registering fareboxes, was compared to accurate counts taken by on-board checkers. Some of the counts read from the fareboxes are wildly inaccurate, probably for reasons other than driver error. If these are eliminated, the remaining counts average 94 percent of the true count. Patterns of error were found that suggest the possibility of developing correction formulas. Low driver counts correlate with high monthly pass usage, low use of cash fares in general, and high measured average cash fares.

The most obvious item of data needed to monitor transit service is a count of the patronage on each route. Yet obtaining accurate passenger counts remains a difficult problem for many properties. Methods used to count passengers include manual counts by drivers (every day or on selected days), counts by drivers aided by electronic fareboxes, special counts by checkers, estimation from loads observed from the street, counts by automatic passenger counters, and estimation from revenue based on average fares.

Many smaller operators, and some larger ones, are fortunate to have the cooperation of their drivers in routinely counting passengers on every run. In some cases this is done by operation of one or multiple counters (for various fare categories), with manual notation of the counter readings at specified times or locations. An example of a large operator that uses this method is the Port Authority of Allegheny County, in Pittsburgh, Pennsylvania. In other cases, including AC Transit, the process is more automated.

PROBLEMS WITH DRIVER PASSENGER COUNTS

Driver counts have the advantage of producing highly detailed data, and requiring no additional personnel. However, processing such large quantities of data may be time-consuming and expensive. Moreover, the counts may not be as accurate as those taken by personnel who are trained for the task and not distracted by other duties. Drivers, correctly no doubt, will tend to view passenger counting as less important than safe operation of the bus, collecting fares, and attending to passengers' questions and problems. In addition to human error, there are also potential problems with the electronic hardware and data collection system.

SITUATION AT AC TRANSIT

In 1981–1982 AC Transit acquired electronic registering fareboxes, which are now installed on its entire fleet. The fareboxes automatically record revenue as it is deposited. In addition, they have a set of 10 push-button keys which the drivers activate to record passengers by fare category. At the end of each day, an electronic data probe is used to transfer the accumulated counts from each farebox onto a magnetic tape. The tape can be read by the District's mainframe computer to prepare farebox information reports.

The passenger count data from the fareboxes have not been used for official patronage reports due to concerns about their accuracy. Aside from driver errors, inaccuracies can result from farebox malfunction, loss of data when the fareboxes are probed, or failure to probe a bus. When a farebox is not probed, missing data for that day is easily detectable. A less detectable result is that the following day's count will be high because it includes the data for two days.

In 1985, staff of AC Transit's Department of Planning and Research, analyzed typical farebox data to determine the extent of these problems, and to recommend a procedure for overcoming them. They determined that about 25 percent of the farebox readings are either: (a) not matched to a bus number, (b) not distributed by fare type, or (c) unreasonably high or low. Unreasonably low counts produce an apparent average fare which is obviously higher than is reasonable. Unreasonably high counts are general obviously in error, with values in the thousands or tens of thousands. The current computer program for summarizing the counts, automatically flags and separates these erroneous readings.

The planning staff proposed a five-step process for producing monthly passenger count data from the farebox readings:

1. Choose a set of sample days each month for analysis. Days are chosen for which the reported coach count differs by no more than 5 percent from the scheduled number. This is intended to eliminate days with an excessive number of failed or missed probes. The proposal called for choosing 9 to 11 days each month (one school weekday per week, one school holiday weekday, two Saturdays, two Sundays, and all holidays).
2. Locate farebox readings which are either: (a) not matched to a bus number, (b) not distributed by fare type, (c) unreasonably high or low.
3. Replace these readings using appropriate averages, or estimates from revenue as available.

D. Koffman, Crain & Associates, Inc., 120 Santa Margarita, Menlo Park, Calif. 94025. D. Nygaard, A.C. Transit, 1600 Franklin St., Oakland, Calif. 94612. Current affiliation: Nelson/Nygaard Consulting Associates.

TABLE 1 AC TRANSIT RIDECHECK AND FAREBOX COUNTS

Route	Ridecheck Total	Bus Trips	Farebox Count	Monthly Passes	Transfers	Cash Fares	Youth Fares	Revenue
79	303	17	227	64	50	113	56	$100
90/92	184	missing	207	42	54	111	36	$71
72	464	5	441	81	104	256	71	$133
8	93	14	111	43	8	60	26	$29
66	143	11	130	33	43	54	20	$47
7	118	5	247	23	7	217	13	$37
40	326	4	279	85	53	141	37	$102
68	45	9	34	11	11	12	7	$10
78	297	9	296	14	95	187	139	$70
82	720	7	707	186	174	347	76	$217
46	154	28	46	3	3	40	29	$23
67	111	4	259	98	60	101	47	$64
80	163	11	170	41	27	102	42	$77
55	424	26	199	65	6	128	45	$102
56	212	9	180	94	30	56	22	$49
93	364	11	334	69	104	161	54	$121

4. Adjust for consistent undercounting by drivers by increasing the totals by 5 percent.
5. Factor up the total for each type of sample day to the total number of weekdays, Saturdays, Sundays and holidays in the month.

Most of this procedure could be automated, although staff would need to choose the sample days, and occasionally recalculate the average fare used to spot low counts in step 2. The staff proposal shows that, even though counts are taken every day, the quality of the resulting data is such that systemwide counts are only possible on a monthly average by day type. The system would be capable, however, of producing route-level counts daily, although some days would have missing data.

ACCURACY OF FAREBOX COUNTS

For this study AC Transit made 20 ridechecks that covered all activity by one bus for a full day. The farebox reports are also based on full-day bus runs. All the checks were on local service, within AC Transit's primary service area. Patterns of errors may be different among service types. In particular, it is likely that counts are more accurate on long express runs than on local runs with heavy boarding and alighting at many locations along the route. It had been hoped to conduct 20 ridechecks on each service type, including two types of express service, and low-density suburban service. Due to the difficulty of scheduling the checks, AC Transit chose to wait for analysis of the first set of checks before proceeding with the others.

Unfortunately, four of the 20 ridechecks could not be matched with corresponding farebox readings. In two cases, the corresponding readings were missing from the data file.

A summary of the ridecheck, and corresponding farebox data, is shown in Table 1. Figure 1 graphs the accuracy of the farebox counts, represented as the ratio of the farebox count to the ridecheck count. The ridecheck count is assumed to be correct. For 12 out of the 16 matched counts, the farebox count is between 75 percent and 119 percent of the ridecheck count. These may be considered "reasonable counts."

More farebox counts are low than high. This makes sense. In fact, it is hard to see how the drivers could produce a high count at all. The 12 "reasonable" farebox counts equal 94 percent of the corresponding ridecheck counts on average. The total of the farebox counts for the 12 routes is also 94 percent of the corresponding 12 ridecheck totals. In other words the farebox counts are low by 6 percent. This figure has a statistical margin of error of about 4 percent. Therefore, the 5 percent adjustment factor recommended by the Research and Planning Staff was a good conservative value.

For four of the 16 cases, the farebox count is high or low by at least a factor of two. In the case of the farebox counts which are high by a lot (Routes 7 and 67), the error is probably in the comparison process. For example, the farebox readings may include an unscheduled midday run, in addition to the morning and evening trippers that were ridechecked. The two extremely low farebox counts (Routes 46 and 55) appear to be due to transfers not having been counted at all. Both of these routes normally experience a high percentage of transfers, but the farebox readings show hardly any.

These analysis results support the recommendation of the Research and Planning staff. They show that, if obviously incorrect farebox readings are removed, the remaining data are accurate enough, on average, to provide a basis for systemwide patronage reporting.

PATTERNS OF ERROR

There are several factors which could be expected to produce errors of varying magnitude. Drivers are instructed to record a count for each boarding passenger. However, even in the case of cash-paying passengers, the driver does not have to enter a count in order for the farebox to accept the fares. A number of passengers paying discount fares could be recorded as a smaller number of full-fare passengers. Passengers paying to retain a transfer, and passengers paying a reduced fare along with a BART transfer, could be substantially under-

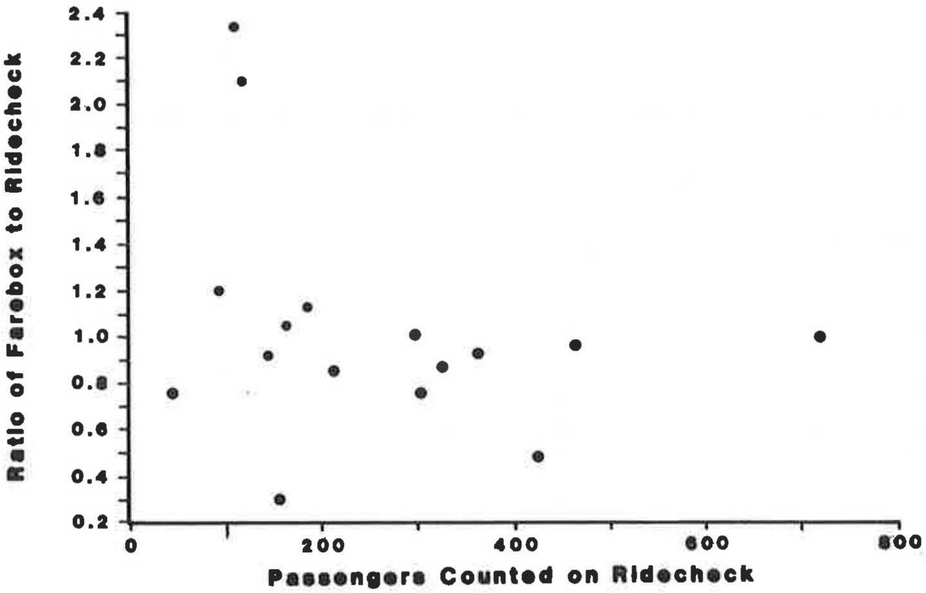

FIGURE 1 **Passengers counted on ridecheck.**

counted. (Transfers are free if the passenger surrenders the transfer slip, otherwise they cost 50 cents.) Both passengers paying with and surrendering a transfer, and passengers paying with a monthly pass are supposed to be recorded on the same farebox key. However, observations indicate that many passengers who do not pay a fare do not get recorded. The severity of undercounting due to any of these factors would be expected to be worse for high patronage levels than low patronage levels because large loads would create greater distraction from the counting task.

Figures 2 through 7 show plots comparing the extent of counting error (expressed as the ratio of the farebox count to the ridecheck count) to various factors which are suspected of contributing to undercounting. Only the 12 cases based on "reasonable" farebox counts are included. As this is a very small sample, all the conclusions here are very tentative. In considering the results, also recall that the reported distribution by fare category is probably in error, due to the influences just discussed. Some of the plots show definite patterns and some do not, as follows:

1. A low percentage paying cash fares of any type is associated with a lower farebox count. This is as expected.
2. A high percentage paying with a pass is associated with a lower farebox count. This is as expected.

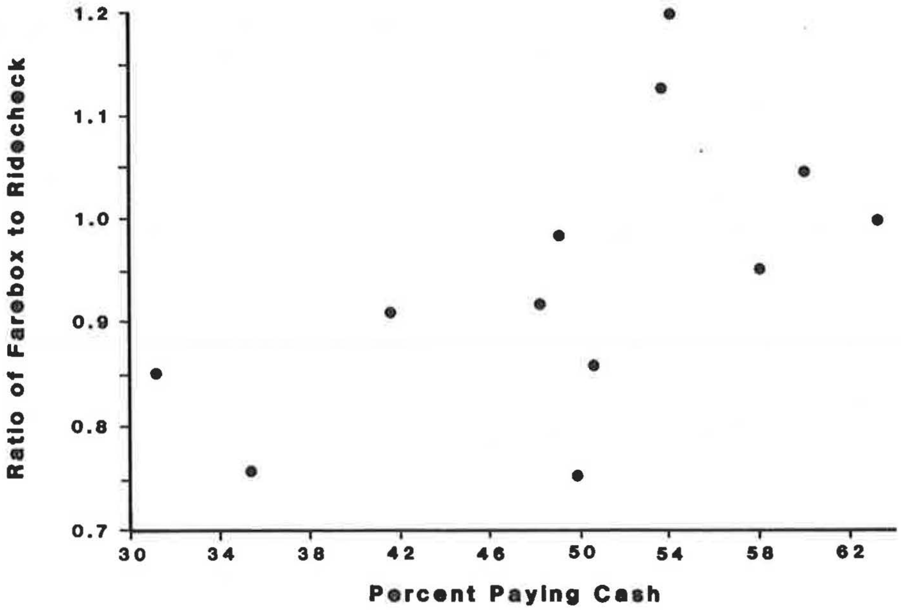

FIGURE 2 **Percent paying cash.**

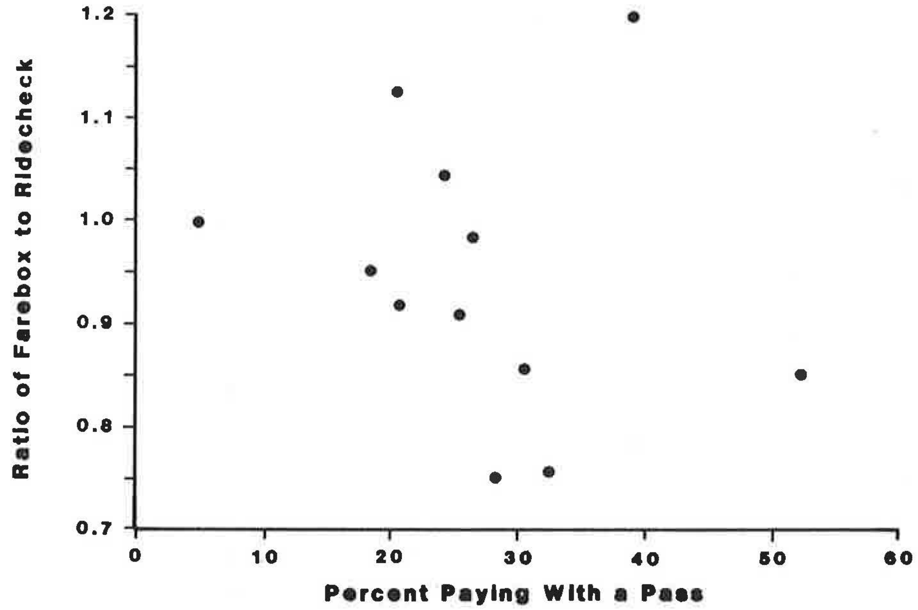

FIGURE 3 Percent paying with a pass.

3. The relationship with the percentage paying with a transfer is very weak.

4. There is no relationship with the percentage paying youth fare.

5. There is no relationship with total patronage.

6. There is a very strong relationship with average cash fare. A high average cash fare is associated with a lower count. On one level, this may be taken as a simple statement that an undercount necessarily produces a high estimate of average cash fare. In terms of the mechanism responsible, it may indicate that multiple discount fare patrons are being counted as a single full fare patron.

The strength of these relationships was tested by fitting regression lines to the data. The resulting equations might, in principle, provide the basis for correction formulas that would be an improvement on the simple 5 percent adjustment factor currently recommended. The results showed that the relationships with percent paying with a pass, and percent paying with a transfer are not statistically significant. Significant relationships (at the 95 percent confidence level) were found only with percent paying cash, and average cash fare. The estimated equations are:

$$\text{RATIO} = 1.3 - (0.54)\,(\text{Avg. Cash Fare}) \qquad R^2 = .45 \qquad t = -2.8$$

$$\text{RATIO} = 0.54 + (.008)\,(\text{Pct. Cash}) \qquad R^2 = .33 \qquad t = 2.3$$

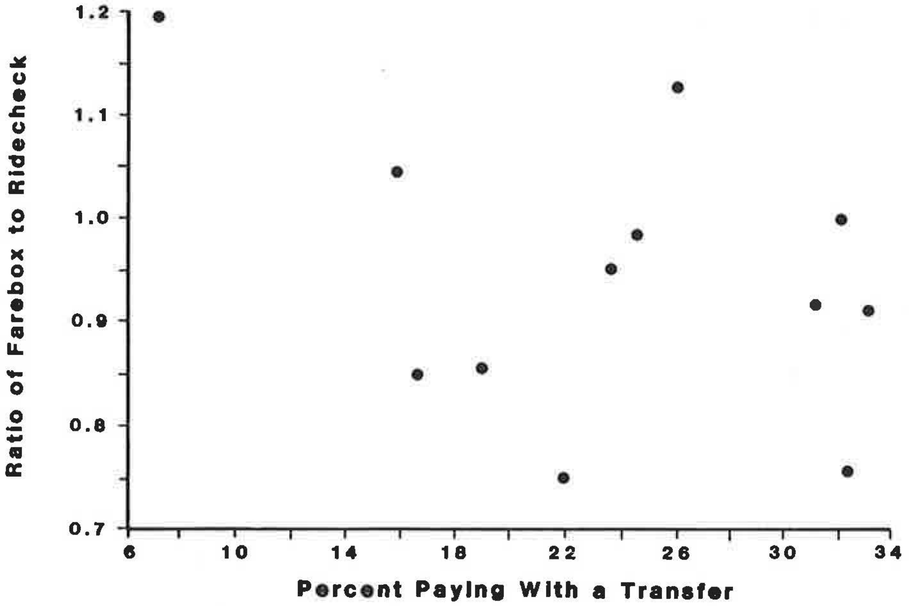

FIGURE 4 Percent paying with a transfer.

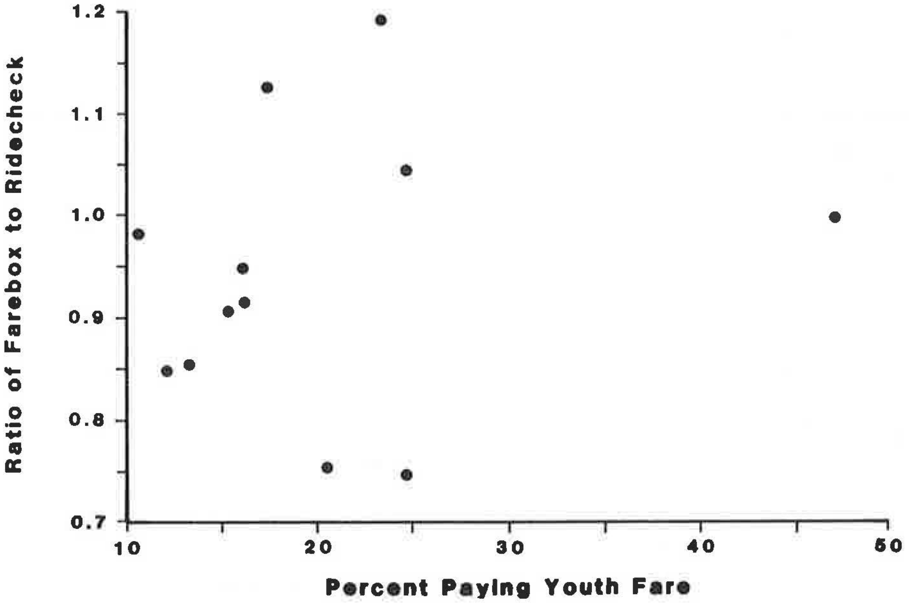

FIGURE 5 Percent paying youth fare.

Although percentage paying by pass, or with a transfer, had no significant relationship when tested alone, when combined they are both significant (at the 90 percent and 95 percent confidence levels respectively), with the following estimated equation:

$$\begin{aligned} \text{RATIO} = 1.45 &- (.008) \times (\text{Pct. Pass}) \\ &\quad (t = -2.1) \\ &- (.013) \times (\text{Pct. Transfer}) \\ &\quad (t = -2.5) \\ &\qquad R^2 = .44 \end{aligned}$$

However, much of the relationship with the percentage paying by transfer is due to one extreme observation (Route 8). When that observation is removed, the relationship with percent paying by transfer becomes not quite statistically significant. The relationship with percent paying by pass is unaffected.

This analysis shows that there are definite patterns to the errors in the farebox counts. However, more observations would be needed before any useful correction formulas could be estimated. All the observations analyzed were for urban local service. In all likelihood, different relationships apply for other service types.

PLANS FOR THE FUTURE

Initially, AC Transit plans to implement the original planning staff proposal. In addition, the District plans a two-pronged

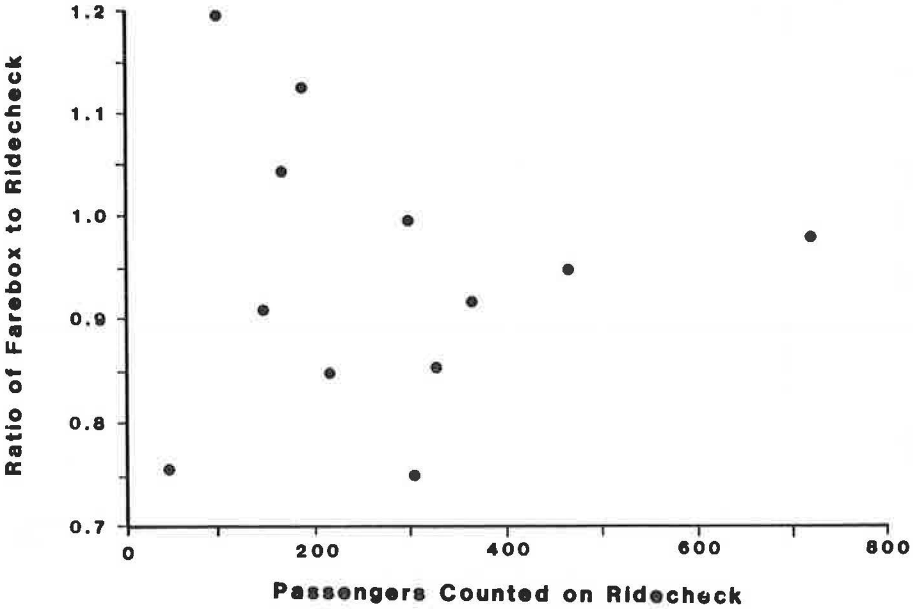

FIGURE 6 Passengers counted on ridecheck.

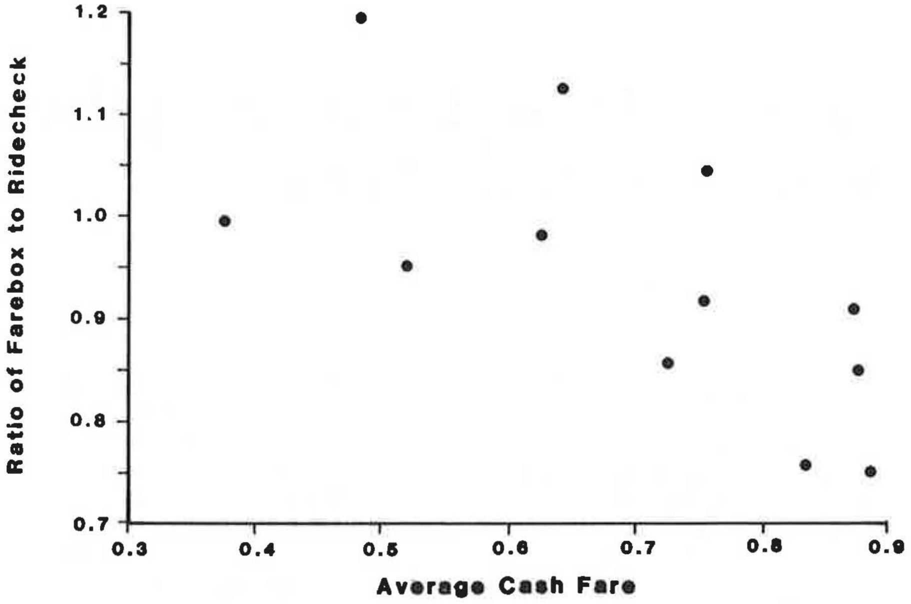

FIGURE 7 **Average cash fare.**

program to improve the accuracy and usefulness of the farebox patronage reporting system. The two parts are as follows:

1. Investigate the behavior of the drivers and the characteristics of the farebox counting system in more detail. This investigation would show which influences discourage the drivers from counting accurately. Besides providing a better basis for interpreting the data, and would provide a foundation for efforts to encourage more accurate counting.
2. Assemble a larger sample of matched farebox counts and accurate independent counts in order to estimate reliable correction formulas. An ideal system would combine use of fareboxes capable of trip-by-trip registration with regular Section 15 ridechecks.

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Multi-Centered Time Transfer System for Capital Metro, Austin, Texas

J. J. BAKKER, J. CALKIN, AND S. SYLVESTER

This paper describes how a radial bus route system was modified into a multi-centered timed-transfer bus network. The intent was to modify the transit network to fit the modern city, which has many centers in addition to the Central Business District. The system is particularly applicable for cities that have a low density of development with typical midday bus headways of 30 minutes. Some implementation problems occurred, particularly because no off-street facilities were obtained. The locations that were established are either on street or on a shopping center. It is concluded that existing networks can be adapted into a Timed Transfer System, and that for systems with long headways network optimization is more critical than route optimization.

The Capital Metropolitan Transportation Authority (Capital Metro) was voted into existence on January 19, 1986, when the citizens of Austin, Texas and several adjacent jurisdictions voted themselves a one-cent sales tax for transit service. Officially Capital Metro took over responsibility for providing transit services in the capital region on July 1, 1985.

Before the vote in January 1985, an interim board had supervised a study to give Capital Metro a Service Plan (*1*). The interim board also visited a number of cities in August 1984 to see for themselves how other cities provide transit service. One of the cities visited was Edmonton, where the interim board viewed the operation of the Timed Transfer System, as well as the Light Rail Transit line.

SERVICE PLAN

The Service Plan for Capital Metro (*1*) tried to correct the ills of an underfunded system. The Austin Transit System of approximately 85 buses served a population of about 500,000. Service usually meant a headway of 40 to 60 minutes midday and 20 to 60 minutes in the peak. The Austin Transit System interlined a number of routes, forming a kind of figure eight. Unfortunately these long routes were subject to traffic delays, adherence to schedules was characterized by a certain randomness. Needless to say, patronage was low.

The vote to approve a one-cent sales tax showed that the population of Austin wanted something better. The Service Plan recommended that Capital Metro provide clock headways with a midday headway of 30 minutes and 15 minutes in the peak if justified. Also, it recommended increasing the size of the bus fleet in service during the peak hour to 314 fixed route buses, 21 Dillo buses (a downtown bus that looks like a streetcar trolley) and 14 or more Special Transit Service buses for the mobility impaired by mid-1988. The Service Plan recommended numerous new routes, including several crosstown routes and Transfer Centers.

In May 1985 the Capital Metro Board authorized a study to see whether the Service Plan could form the basis of a Timed Transfer System for the Austin area (*2*). It was concluded that with modifications, the Service Plan could serve as a basis and a Timed Transfer Concept (Figure 1) was accordingly developed. The study was followed by an Implementation Study (*3*) for the Capital Metro Service Area. This paper deals with the development of the Timed Transfer Concept plan, as well as the difficulties encountered with implementation.

MODERN CITY

It is probable that a substantial difference exists between the City as it actually is and as it is perceived. Many planners and transit operators view the city as having a Central Business District (CBD) surrounded by reasonably dense development. This area is usually provided with a fixed-route radial type of transit system. Surrounding this "perceived" city is suburbia, which is difficult to serve and which is often ignored by transit operators.

The actual city is more dynamic than generally assumed. It may still have a CBD, either declining or in the process of renewal following a decline. The pattern has often been that central city residents migrated to the suburbs. However, some renewal is occurring closer to the city center. As shopping centers of various sizes develop in the region, they are assuming the characteristics of mini-business districts. Lately, office centers have also been locating throughout the region.

The City of Austin is a perfect example of this dispersed development: it has experienced very rapid growth in the past two decades and shows CBD renewal as well as the development of regional centers.

For a transit system to serve only the CBD means limiting its potential market. If the city has become multi-centered, the transit system must serve these multi-destinations as well. The Capital Metro transportation system of Austin will provide a rare opportunity to observe the following:

1. How the transit network was adapted to serve a multi-centered city, with a Timed Transfer System, and
2. Whether transit patronage increased.

J. J. Bakker, Department of Civil Engineering, University of Alberta, Edmonton, Alberta T6G 2G7, Canada. J. Calkin, Capital Metro, 1005 Congress Avenue, Austin, Tex. 78701. S. Sylvester, Capital Metro, Austin, Tex. Current affiliation: Regional Transportation Authority, Phoenix, Ariz.

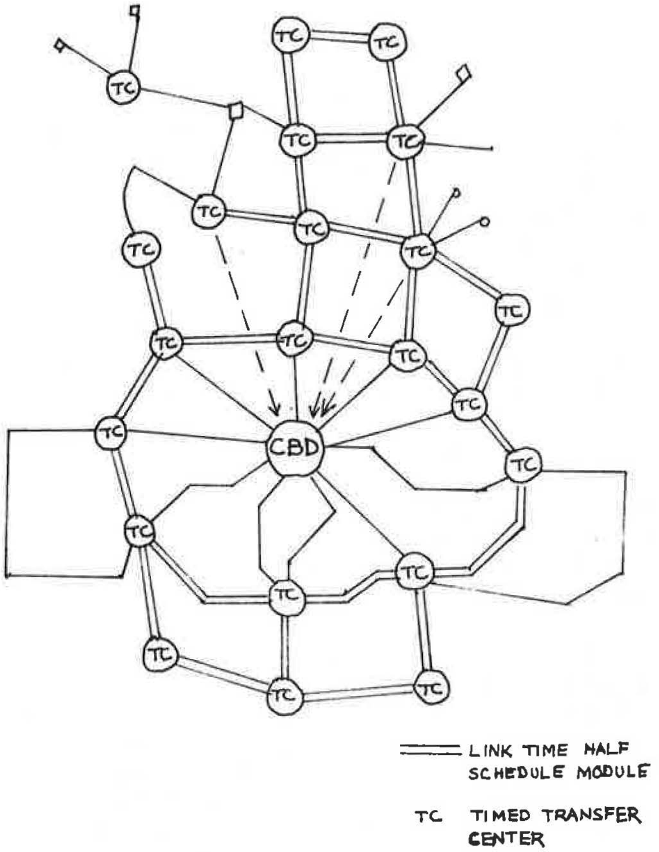

FIGURE 1 Timed transfer concept.

This paper will confine its discussion as to how the transit network is being adapted into a Timed Transfer System. The adaptation will require two or three years, because land has to be acquired for some of the proposed Transit Centers. The effect on patronage cannot be measured until two years after full implementation.

TIMED TRANSFER CONCEPT

In a Multi-Centered Timed Transfer Network, transit tries to provide opportunities for travel from any given point to any other given point. The aim is for all transit routes (Rail, LRT, Bus, Paratransit) to meet simultaneously at the same location at regular intervals (preferably the same minutes past the hour). To accomplish this, routes and schedules have to be developed together. In many cities in the western United States and Canada, as well as the suburbs of older cities, the density of development is low. The result is that the headway that can be justified at midday is usually 30 minutes. In peak hours the service is more related to demand volumes and service is therefore more frequent. A Timed Transfer System would not be the system to choose if the density of development is such that frequent service (or headways of 10 minute or less) can be provided all day.

If the headway is 30 minutes, buses would meet along a route every 15 minutes. Allowing for a layover/recovery time of 3 minutes, a meet could occur every 12 minutes of travel time. At that location, crosstown routes and/or feeder routes could also meet. In fact, with a Timed Transfer Network, a kind of super-grid develops with transfer locations about 12 minutes travel time apart. By locating the (Timed) Transfer locations some distance away from the CBD, the crosstown distances between centers can also be 12 minutes of travel time and form a circle or square, the circumference of which is (h times 12) minutes for each side. In any particular system this circle need not be closed. Consideration should also be given as to whether express buses are justified from the first and/or second rings of Transit Centers.

DEFINITIONS

The definitions used in the transit industry vary greatly, so the same definitions as used by Vuchic in his books and manuscripts (*4, 5*) will be used here.

h = headway
h_p = pulse headway, also called schedule module
h_i = headway of individual route
j = integer
L = route length
N = number of buses or vehicles, $N = T/h$
T = cycle time, equal to 2 sum of ($T_o + t_t$)
T_o = travel time = (operating travel time)
t_t = terminal time (layover/recovery time)
V_c = cycle speed (V_c for cycle is $120 \cdot L/T$)
V = operating speed ($V_o = 60 \cdot L/T$)

For transfer meets to occur, $h_i = j \cdot h_p$ or any individual headway has to be equal to or be a multiple of the pulse headway or schedule module.

For clock-headways, 60 minutes $= j \cdot h_j = j \cdot p$. The schedule will repeat at the same minutes past the hour.

For travel time between centers, $j\ (T_o + t_t)/2 = j \cdot h_p/2$. The travel time must be equal to or be a multiple of half the schedule module, which is equal to the pulse headway or sum of operating time plus terminal time.

For travel time for a feeder route, $= h_p \cdot j - t_t$

DEVELOPING THE TIMED TRANSFER CONCEPT

A Timed Transfer Concept is developed by starting at one specific location—a shopping center, for example. From this location there would be one or more radial routes to the central business district (CBD). The possibility of there being more than one route arises from the fact that adjacent radial routes may be changed to go to the same Timed Transfer Center. The second set of routes developed would be crosstown routes. Using the road system available, several 12-minute travel time distances are plotted, to determine suitable locations for other transfer centers. The third set of routes would be feeder routes serving residential, industrial or office areas. The possibility of establishing express routes from the transit center to the CBD or another major destination, such as a university or government center, should also be explored. This express route could be a peak hour-only service or an all-day service, depending on demand.

In Austin the starting point was Highland Mall (H) (see Figure 2). From this mall it was possible to reach Windsor Park (or Capital Plaza) (D), Hancock Center (E) and North-

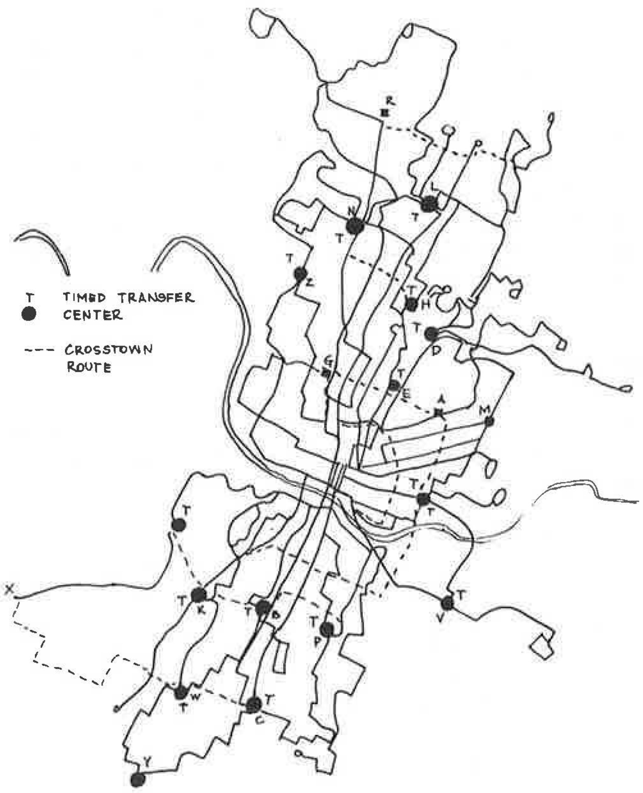

FIGURE 2 Proposed multi-centered time transfer system.

cross Mall (N) (via Justin Avenue) in 12 to 17 minutes. Northcross Cross Mall and Windsor Park were then used again as starting points to locate the next set of transfer centers. From Windsor Park these were MLK/Springdale (M) and the municipal Airport (A); from Airport and Springdale/MLK the next center is East 7th and Pleasant Valley (T), the next one is Vargas and Riverside (V), from there IRS/I.H.35 (P) and so on along the Ben White Crosstown route to Radam (B), Westgate (K) and Barton Square Mall (F).

It is preferable that transfer locations in a Timed Transfer Network be off-street, so that passengers can transfer between buses safely as well as quickly. On-street transfer locations should be viewed as temporary. Transfer locations are often located at existing or proposed activity centers such as shopping malls, colleges or universities, hospitals, or stadiums. However, a park-and-ride lot near the intersection of a freeway or arterial road may also be a good location.

With a Timed Transfer System, it is also possible to develop a kind of super-grid beyond the first set of Transit Centers. The sides of the links in this super-grid have a length of $(h_p - t_t)/2$, or for a 30-minute module, about 12 minutes' travel time. The links in the super-grid can form a square or a rhombus.

The travel times to the CBD are not necessarily critical. The main control is that the round trip time of any route is either equal to h_p or a multiple of h_p. For a 30-minute module that means 30, 60, 90 or n times 30 minutes. Sometimes two routes of 45 minutes can be combined and give a total of 90 minutes total round trip time. All these travel times are taken midday which is the design period.

In the CBD the transit routes can be concentrated on one transit street or transit mall, or can be dispersed over a number of streets. It all depends on the land use and the shape or layout of the City Center. Smaller cities may also have a Timed Transfer Center downtown. In the case of larger cities that may not be desirable because of traffic congestion. An example of having a downtown transfer center is Saskatoon, Saskatchewan, Canada; here one downtown block has been converted into a transit mall, where all routes meet at the same time.

It is more usual for larger cities to link routes on either side of the CBD and create a diametric route, depending on travel time and passenger demand. The regular transit routes may be complemented with downtown distributor routes which operate frequently: in Austin the Dillos fulfill this function.

From the foregoing discussion, it can be seen that travel time and terminal time are the critical components. The design should be based on the basic midday service, because there is usually a more frequent service available during the peak hours. For that reason special attention must be paid to scheduling, in particular since routes and schedules are developed together. For a Concept Plan average speeds can be used; however, implementation requires simulated test runs in actual traffic conditions.

In a Timed Transfer System there is also some flexibility when overloads occur. For example, if a feeder bus overloads a main line bus, the feeder bus should be continued to the CBD or any other major trip attractor (CBD, Government Center, University) in addition to the main line bus. The possibility of running the feeder bus continuation express or limited stop should also be investigated. Continuing a number of feeder routes would lead to the platooning of buses, an alternative which may be preferable to that of providing more frequent service. First transfers are maintained to crosstown routes, but the demand may vary between summer and winter (university in session), allowing more or less through running. In other words supply can more easily be matched to demand, without having to reissue timetables, with the connection still in place.

In Edmonton, Alberta, feeder buses have been extended in the peak hours from Transit Centers as express runs, and in some cases there are six feeder routes that have to be continued, forming platoons of six buses at a time. It is of course possible to replace these six buses with one L.R.T. train at a later time.

Feeder routes can serve more than one Timed Transfer Center. For example, a direct route between two Transit Centers requires 12 minutes of operating time and 3 minutes' terminal time. A feeder route linking the same two terminals could take 41 minutes operating time with 4 minutes' terminal time.

One of the big advantages of a Timed Transfer System is that further route development can take place incrementally from any Timed Transfer Center. The only requirement is that the feeder route has a round trip length equal to (schedule module or pulse headway minus terminal time). For a 30-minute schedule module this round trip travel time would be about 26 minutes.

In addition, feeder routes can also be become demand-responsive during low patronage periods and could be combined with Special Transit Services operations, which are services for the mobility-impaired.

SCHEDULING APPROACH OF TIMED TRANSFER SYSTEM

In a timed transfer system routes and schedules are developed together, and transit centers must be located equidistantly from each other in terms of travel time; therefore linear optimization is not as easy as in other types of transit networks, where routes are developed individually. Timed Transfer means that the problem of optimization is not linear but two-dimensional. Timed Transfer is designed to confer travel opportunity, and therefore holds the potential of more patronage. Waiting time is evaluated by the passenger as four times that of riding time, an evaluation that does not show in linear scheduling optimization. The philosophy here is: "It is better to operate with a little less bus and schedule optimization and have passengers in the buses, than to have schedule optimization and empty buses."

By placing the layover/recovery time (terminal time t_t) at the transit centers, the randomness along the route can be reduced, which greatly improves schedule reliability.

For Timed Transfer to work there is a need to obtain reliable running times for the various times of the day. The midday period will be used for design. Layover time should occur only at the Transit Center and nowhere in between. Buses should never run ahead of schedule, so that operating time should be established in such a way that it would be impossible to run ahead of schedule. In other words for on-time performance it is better to set the operating time sharp and increase the terminal time. In practice, it may mean that the bus will arrive a few minutes late into the terminal. However, because of the increased terminal time, connections can still be made.

There are a number of different transit markets that should be kept in mind, such as the following:

1. To relieve peak hour traffic.
2. To relieve parking demand, particularly at major activity centers. (Both 1 and 2 are the better use of scarce space.)
3. Service to those who do not want to drive.
4. Service to the mobility-impaired (this service may be on regular transit or Special Service Transit).

For these markets there are different time periods that require different intensity of service. These periods are differentiated by the following:

Period 1. Offices and other places of work opening and closing for their employees (the a.m. and p.m. peak hours on weekdays, Monday through Friday).

Period 2. Time that offices and stores are open [midday].

Period 3. Time that offices are closed and stores are open. (This is the case in the evenings Monday through Friday, from 11 a.m. to 6 p.m. on Saturdays, and increasingly in the afternoons on Sundays and holidays.)

Period 4. Time that offices and stores are closed. (Early Saturday, Sunday morning, Sunday evening and late evening Monday through Saturday.)

The scheduling periods shown in Table 1 should therefore be considered. These times may differ in each community, in that stores may or may not be open on Sundays and holidays. Also store opening times on Saturdays vary; in some communities stores are closed on Saturday evening. The latest service should be able to cater to the last movie-theater performances. The type of equipment used should be related to the demand.

TRAVEL TIME CHANGES

On current bus routes, the operating time can be determined by a "speed and delay" study on board the bus. In new areas a simulated transit run should be made. In the case of proposed subdivisions, average speeds in similar areas should be used. In developing a "concept plan" average speeds can be used; however, when the functional plan is developed actual running times must be used. In the peak hours travel time may increase due to traffic congestion. Again, speed and delay studies should be made. On the residential feeder routes more time may be required in the morning peak hour since there will be more boardings and fare transactions. This delay can be reduced by the use of passes or multiple ride tickets. Usually the midday running times remain feasible during the peak hours on feeder routes.

However, bus routes along radial and arterial roads will suffer from traffic delay. The running time chosen here should permit the vehicle to be on time.

If the frequency of service is doubled in the peak hours, the headway is halved. It then becomes possible to increase operating time. For example, the sides of the super-grid (operating time plus terminal time) in a congested region may be increased from 15 minutes to 22.5 minutes, since meets with a headway of 15 minutes occur every 7.5 minutes.

There are two primary concerns with a Timed Transfer System: what happens when travel time increases and what if travel time decreases. Each of these problems can occur permanently, temporarily or occasionally.

TABLE 1 SCHEDULING PERIODS

Day of Week	Time of Day					
	6–9 a.m.	9 a.m.–Noon	Noon–3 p.m.	3–6 p.m.	6–9 p.m.	9 p.m.–Mdnt.
Weekdays	a.m. Peak Period 1	Midday Period 2	Midday Period 2	p.m. Peak Period 1	Evening Period 3	Night Period 4
Saturdays	Early Sv. Period 4	Midday Period 3	Midday Period 3	Midday Period 3	Night Period 4	Night Period 4
Sundays	Limited service	Early Sv. Period 4	Midday Period 3	Midday Period 3	Night Period 4	Limited service
Holidays	Limited service	Early Sv. Period 4	Midday Period 3	Midday Period 3	Night Period 4	Limited service

Travel Time Increases

The first step is to analyze, by implementing a speed-and-delay study aboard the bus, the real cause of the increase in travel time. Sometimes the cause may be transit operations, such as poor schedule adherence by the driver, or the driver's stopping the bus for a cigarette or other type of break, or poor schedules. If the cause is traffic signals, then the answer should be found in traffic management. However, other solutions are also possible, such as reducing the number of bus stops along the route from every block to every other block.

Other approaches are as follows:

1. Establish far-side bus stops.
2. Study specific bottlenecks, whether lanes be added or whether transit can be given special priority. One of the easiest methods is to institute a "right turn lane only," except for buses. This solution goes well with establishment of a far-side bus stop bay.
3. Reduce signal cycle times. In many cases there is a mistaken belief that longer cycle times are more efficient and that more phases improve efficiency. Phases and cycle times should be reduced whenever possible.
4. Investigate the type of fare systems that will speed up boarding, such as passes, multiple ride tickets, and similar means. Other passenger-handling techniques, such as boarding through more than one door, should also be investigated.
5. Reduce terminal time.
6. Increase route length and add a bus, or decrease route length.
7. Increase speed.

An occasional increase in operating time requires incident management. If the delay is less than 5 minutes, the connecting routes should hold. If it is more than 5 minutes, it will depend on the headway of the connecting route. If h_i is 15 minutes or less, after 6 minutes the bus could leave; otherwise it may hold, particularly in the evening peak hour and a chance that the next bus will also be late.

Travel Time Decreases

Travel time usually decreases when few stops have to be made, as in late evening, Saturday mornings, Sundays and holidays. The answer here usually is to combine feeder routes or to combine a feeder route with a radial route. Feeder routes can also be replaced with a demand service for an area. If travel time decreases, the route can also be lengthened.

IMPLEMENTATION PROBLEMS

Introducing major route and schedule changes in a transit system can be traumatic. Capital Metro tried to implement two Timed Transfer Centers in July 1986, Windsor Park and South Congress. Neither succeeded because the land for an offstreet site was not available.

In Windsor Park initial public meetings did not show any opposition. However, when a temporary on-street location was chosen, the opposition was vocal. This center was therefore postponed, and in later planning relocated to a nearby shopping center.

The South Congress site was not obtained, so the center was temporarily located about 4 minutes' travel time further east, next to a shopping center. This temporary location is Capital Metro's first official timed transfer center. Five routes pulse into the South Transfer Center every 30 minutes. However, the temporary location causes some backtracking and duplication of certain routes.

Major changes introduced in July 1986 also introduced some additional transfer locations, mainly at shopping malls. At the same time, clock headways were introduced on all routes. An additional 100 buses were added to the bus fleet to accomplish these changes and other service improvements.

Major complaints arose where long routes were cut into segments and transfers were not timed properly. In defense of the scheduling and operations sections, it must be noted that their task was not an easy one, as it involved rewriting all schedules, doubling the service, introducing new routes and developing all schedules, using a newly introduced computer package. The most serious deficiencies were rectified soon after implementation of the July 27, 1986 changes.

NEXT PHASES

The next two phases were to be implemented in 1987. The first problem was to acquire offstreet sites at South Congress, Capital Plaza Shopping Center, and near Mearns Meadow. The second aspect was to use existing transfer locations as part of the overall Timed Transfer plan.

The second aspect was implemented first, as the lead time was less and could be started more easily. Four locations on the north side of Austin became Timed Transfer Centers, two of which are on-street (Northcross Mall and Mearns Meadow) and two are on shopping centers (Highland Mall and Hancock Center). It is possible that one of the on-street sites will be transferred to a shopping center (Northcross Mall). As a result of the four northside centers, one on-street southside transfer location will also be established (Vargas/Riverside).

The second stage of implementation has to wait until the two off-street sites are completed. One will be on a shopping center (Capital Plaza) and is the one that replaces the Windsor Park site that caused local neighborhood opposition. The second one is South Congress (being moved from its temporary location to the original intended site), which will make the implementation of four more on-street Timed Transfer Centers possible on the south side. The Capital Metro Board has failed, however, to approve either the acquisition or long-term leasing arrangements for off-site Transit Centers.

Southside Implementation

The southside implementation is a good example of the necessity for Timed Transfer and why it results in network optimization rather than route optimization.

Ben White Crosstown Example

The No. 28 Ben White Crosstown route goes from the IRS office complex next to Interstate Highway 35 along Ben White to a regional shopping center called Barton Square Mall. In the process it crosses six radial routes.

In July 1986 the No. 28 Ben White Crosstown route operated using the minimum number of buses to go from one end of the route to the other without attempting to "time connect" with any of the six radial routes. Figures 3 and 4 give the previous and current situations, as well as the proposed route change. Table 2 shows both current and new delays experienced by passengers who attempt to transfer. Needless to say, under the current situation the route carries few passengers.

The southside changes propose to change the ends of the route into two Timed Transfer Centers (P and F) and to deviate the No. 28 route into two more Timed Transfer Centers (B and K). The first is the South Austin Community Hospital (B), one block south of Ben White. A timed meet can be designed initially on-street on Radam Lane. The second deviation is at Westgate (K) Shopping Mall, again one block south. Because a layover time of 3 minutes is introduced at both timed transfer locations, and because the route deviates from a straight line, the total travel time will increase by 12 to 15 minutes end to end, requiring an additional bus to maintain a 30-minute headway. At the same time, some radial routes would be diverted into the newly created Transit Centers.

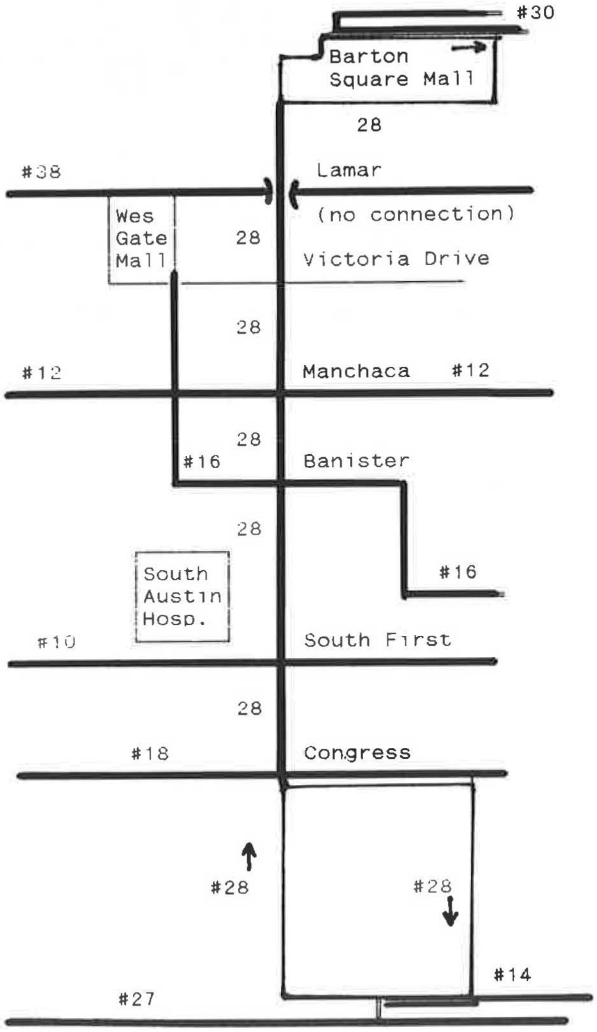

FIGURE 3 Ben White Crosstown example: before timed transfer bus network.

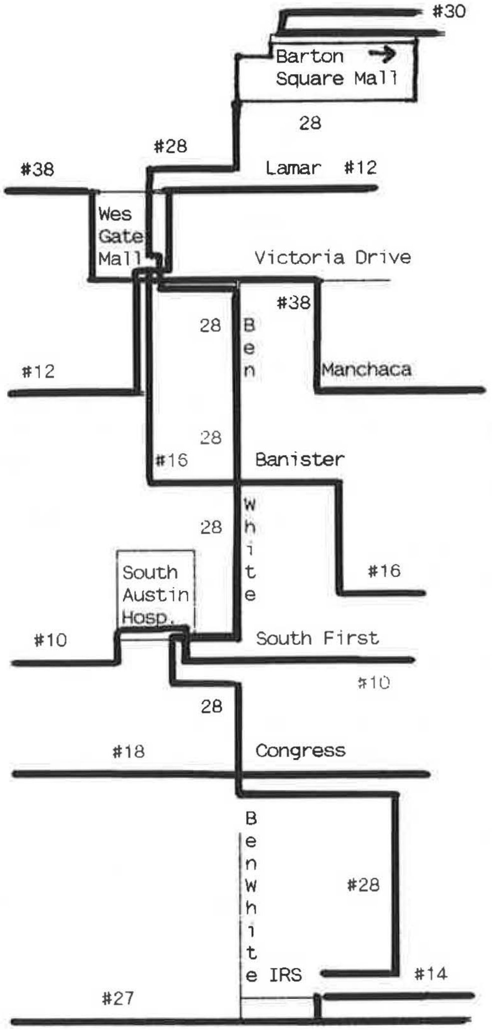

FIGURE 4 Ben White Crosstown example: timed transfer network.

In the "before" situation the short transfer times were usually matched with the long transfer times in the opposite direction. Clearly, from a passenger perspective, the proposed alternative is better; particularly if waiting time is evaluated as about four times riding time by the passenger.

Bus Requirements

The Service Plan (*1*) predicted a need of 314 peak hour vehicles by 1988 from the 67 that were operated in 1984. After the July 1986 changes, 194 buses were in service. The Timed Transfer Plan will not differ in vehicle requirements: together with other service improvements, the recommended plan will require 287 peak-hour vehicles. The Capital Metro Service Area is quite a dynamic region and additional service will be required in several areas, so the Service Plan estimate is still valid.

The extra costs associated with a Timed Transfer System are the off-street transfer facilities or Transit Centers. The

TABLE 2 CURRENT AND PROPOSED DELAYS IN TRANSFERRING

	Transfer Delays (min.)	
Location	Current	Proposed
Barton Square Mall	1, 8, 17, 22	4, 5, 19, 20[a]
Westgate	no service	3 (all routes)
Manchaca	2, 4, 5, 9, 19, 25, 26, 28	Meet at Westgate
South First	3, 3, 4, 10, 26, 27, 27	3 (all routes at South Austin Hospital)
I.R.S.	7, 8, 11, 13, 22, 24	3 (all routes)

[a] Subject to review.

plan at present is to use on-street space first, as well as already built shopping centers wherever possible. At shopping center locations, some pavement improvements may be required or leasing arrangements may have to be made. Two or three off-street facilities per year were planned for the next three years. The costs of these off-street facilities can vary greatly, depending on land costs, the amount of architecture, and amenities included. It is premature to give exact costs at this time.

CONCLUSIONS

1. Because schedules and routes must be developed simultaneously, it is essential to have current and reliable data regarding travel time.
2. If an off-street facility is planned, it is essential to obtain the land early in the process.
3. It is quite possible to adapt an existing system to a Timed Transfer System, and yet not disturb the existing route structure too much.
4. Linear optimization of scheduling has to yield to the Timed Transfer controls, if a proper transit network is to be established. This is particularly true of systems that have long headways.

ACKNOWLEDGMENTS

The authors are grateful to the Board of Directors and the Executive Director of Capital Metro, Alan C. Wulkan, for the cooperation received in preparing this paper.

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Coordination of Public Transit and School Bus Transportation Programs: Results of Pilot Projects in Six Iowa Communities

MICHAEL KYTE, NANCY RICHARDSON, AND CONNIE MCKEAN

In 1982, the Iowa General Assembly directed the Iowa Department of Transportation to study the feasibility of coordinating public transit services and school transportation programs. Between 1983 and 1985, pilot projects were successfully implemented in six Iowa communities. Four of the projects were located in urban areas and involved shifting students from school bus transportation to city transit services. While school bus transportation generally costs less, it was found that in some cases (as when excess capacity exists on public services) public transit services are more cost effective. Two of the projects were located in rural areas and involved coordinating the operations, maintenance, and purchasing functions of school districts and public transit systems. The participating agencies in both rural projects saved on costs. While the concept of transportation coordination was found to be feasible in all six areas, there are significant legal and institutional barriers to be overcome in each case. Public policy in Iowa has encouraged, and in some cases mandated, coordination between transportation operators, and the public has benefited from such policy.

It is often perceived by policy-makers and public alike that the lack of coordination of publicly supported transportation services is inefficient and wasteful. A frequently cited example is that of a school bus and public transit bus following each other down the same street as they serve the same area of a city or town. In reality, while coordinating services may reduce public expenditures for transportation, there are several significant institutional, regulatory, and operational barriers to be overcome in each case.

In 1982, the Iowa General Assembly directed the Iowa Department of Transportation to study the feasibility of coordinating public transit services and school transportation programs. The authors, in response to this directive, developed and implemented pilot projects in six Iowa communities between 1983 and 1985. Four of the projects were in urban areas (Dubuque, Burlington, Sioux City, and Ottumwa) and involved shifting students from school buses onto public transit vehicles. The other two projects were in smaller towns (Nashua and Spirit Lake) and focused on coordination of operations, maintenance, and purchasing.

The purpose of this paper is to report the results of these six pilot projects. In section 2 of this paper, previous results of school bus and public transit system coordination are described; in section 3, relevant statutes and regulations are discussed, and in section 4, the pilot projects are summarized. The findings of the study are presented in the final section.

PREVIOUS SCHOOL BUS–PUBLIC TRANSIT COORDINATION

In most cities and rural areas in the United States, transportation services are provided by separate organizations rather than by a single agency. Each transportation provider has its own administrative structure, budgeting process, capital development program, cost structure, and labor practices. While city transit and paratransit systems have worked together to some extent, school districts have often operated in a completely separate environment. This is partly due to the evolution of school bus safety standards and funding, and to the assignment of administrative responsibility to separate state agencies, one responsible for school transportation and one for all other transportation operations.

There have been, however, several projects involving the coordination of the transportation programs of public transit systems and school bus operations in the United States. These projects can be divided into two categories.

The first category includes the use of school buses for non-pupil transportation (*1,2*). These projects generally provided transportation for elderly or disabled persons, and were usually implemented in areas where regular public transit service did not exist. Often the success of these projects led to the establishment of a government subsidized or private nonprofit transit operator to provide the service.

The second group involves the use of public transit buses for pupil transportation (*3,4,5,6,7*). Before the advent of yellow school buses, most students in the United States used regular public transit services to travel to and from school. As cities grew and travel patterns changed, public transit services became less relevant to the needs of pupil transportation programs. As costs have increased in recent years, however, there has been a growing interest in investigating the feasibility of shifting pupils from school buses to public transit buses. Some school systems have contracted with public transit systems to transport students, despite federal rules restricting these practices.

STATUTES AND REGULATIONS

There are several federal and state statutes and regulations pertaining to the coordination of school bus transportation

M. Kyte, Department of Civil Engineering, University of Idaho, Moscow, ID, 83843. N. Richardson, Iowa Department of Transportation, Des Moines, IA, 50319. C. McKean, Anamosa, IA 52205.

and public transit. At the state level, Section 601j of the Iowa Code encourages coordination of transportation services by requiring that all purchasers and providers of transportation services, except school districts, coordinate their actions through the Iowa Department of Transportation.

Several sections of this code deal with pupil transportation and the uses of school buses. Local school districts have three options for transporting their students: they can transport pupils directly in yellow school buses, contract with common carriers to provide the service, or reimburse parents for transportation costs. This provision allows a school district to contract with a public transit operator to transport students to and from school, with the school district reimbursing the transit system for the cost of providing the service. The code exempts urban transit buses from meeting certain vehicle standards such as the use of flashing red lights and stop arms. However, other requirements are imposed on the transit operator according to whether the service is used exclusively for pupils. If the service is used exclusively for pupil transportation, the transit operator must, among other things, add temporary school bus signs to the bus, load and unload pupils according to certain requirements, provide seats for all passengers, conduct daily vehicle inspections and reports, and ensure that all drivers possess school bus driver permits and receive special training.

The way in which school districts receive state funds for pupil transportation is also an important consideration. Under Iowa law, each district receives a lump sum from the state with no set amount earmarked for transportation. Thus, districts that are able to reduce the cost of pupil transportation have more money to spend on materials, instruction, and other expenses. This point is important because it strengthens the incentive for school districts to participate in cost-reducing transportation coordination programs.

The issue of exclusive school service is also critical in the federal regulations governing public transit systems. The Urban Mass Transportation Administration (UMTA) specifically prohibits transit systems which receive federal funds from providing exclusive school service. The objective of this regulation is to ensure that transit operators use their resources to serve the general public and refrain from competing unfairly with private school bus operators. The regulations do allow transit systems to operate special school tripper service that is nonexclusive (that is, general passengers are allowed on the buses) and part of regular route service. UMTA has also allowed one transit system (Des Moines, Iowa) to provide exclusive school service after the system agreed to buy out the depreciated federal interest in the buses used for the service.

DESCRIPTION OF THE PILOT PROJECTS

Four pilot coordination projects were implemented in urban areas of Iowa (Dubuque, Sioux City, Burlington, and Ottumwa), each involving the shifting of students from school buses to public transit buses. Project objectives were to reduce the transportation expenditures of the school district, and to increase ridership and revenue for the transit system.

The projects were developed using the following steps. First, groups of student eligible for school bus transportation were identified geographically. Second, potential services that could be provided by the public transit authorities were identified. Finally, these market groups and services were matched.

While there was some interest in shifting the entire pupil transportation program to the public transit systems, it soon became apparent that this was not economically feasible. The major elements that make up the cost structure of the two agencies favor the school district. For example, the school district usually has lower operator labor rates, higher vehicle capacities, a larger bus fleet, and lower per-bus capital costs. In Burlington, Iowa, for example, the cost per seat-hour, a rough measure of the cost of providing service, was 63 percent lower for the school district than for the public transit system ($.21 vs. $.56).

While complete consolidation was not feasible, it was possible to shift some students onto city transit buses where such services already existed with excess capacity. Here, the public transit system had a fixed investment in service and it thus could "sell" its excess capacity to the school district at only marginal costs. This concept proved successful in each of the four urban areas studied. The number of students involved ranged from 200 to 320, while annual cost savings varied from $12,000 to $30,000.

Two projects were implemented in rural areas. In Nashua, Iowa, the pilot project included shared fuel purchasing and service provision. The cost savings of $3,500, although small, were significant for the school district. In Dickinson County, in Northwest Iowa, the school district contracted with the RTA to provide all maintenance for school district buses, resulting in a $6,500 annual savings and an improvement in the quality of maintenance.

FINDINGS

There are seven major findings than can be drawn from the pilot projects:

1. The success in implementing pilot projects in each of the six study areas supports the notion that there are opportunities for transportation coordination throughout Iowa. In urban areas, there is a potential for shifting students from school buses to city transit buses. Although the general cost structure of school districts and city transit operations generally favors school districts, in certain instances it is more cost effective for a city bus system to provide this service. These situations usually occur when the city bus system has excess capacity, when student travel patterns coincide with city bus routes, and when changes (e.g., minor rerouting) in the city bus routes are possible. In small towns and rural areas, opportunities exist for school districts to either coordinate various aspects of their transportation programs among themselves or to coordinate with the regional transit authorities.

2. The philosophy followed in each study area proved successful. That is, it was important to focus on a small project that had a high chance for success and that could be implemented with the support of agency staff rather than developing a larger project (with potentially larger benefits) that would be less likely to gain such support and be unmanageable as a first effort. Once a pilot project was successfully underway, larger projects with greater benefits could then be pursued.

3. The most difficult barrier to coordination is institutional.

More generally stated, there is a high resistance to change among institutions and the persons served by these institutions. While the project philosophy described above was felt to be critical in all of the pilot projects, the size of the projects also meant that the benefits accruing would be small at the beginning. Thus it was often difficult for some agencies to justify their participation simply because the benefits that they would initially receive would be small in comparison to the energy that they must put into implementing a project. In addition, lack of a long-term commitment to coordination was apparent in most of the pilot project areas. While generally agreeing that coordination was a "good idea," most areas lacked one person or group who was truly committed to incorporating the concept of coordination into the normal operating procedures of the local agencies involved in the pilot projects. Such a long-term view is critical if pilot projects are to survive more than just their trial period of operation. It is often necessary, therefore, to have an outside "change agent" responsible for developing a concept and working with the local agencies to implement it.

4. At the state level, there are several legal barriers to coordination that should be examined. First, strict adherence to the transportation level of service standards required by the State Department of Public Instruction for all age groups and all operating conditions should be studied. Two examples are the requirement for a seat for all passengers and the loading and unloading procedures. It is not clear that regulations for high school or junior high school students should be the same as for elementary school students, particularly when city transit buses are used for pupil transportation. Similarly, operating conditions in urban areas are different from those in rural areas, and the regulations should reflect these differences. Second, restrictions on vehicle usage for pupil transportation should be examined. Currently, if the service is nonexclusive, the only requirement is that the transit bus pull completely off the roadway to pick up or drop off a student. If, however, the service is exclusively for students, a number of requirements apply, including the installation of temporary "school bus" signs, state vehicle inspections, and the requirement of school bus operator permits for drivers. The difference in the service lies in the definition of its nature (exclusive vs. nonexclusive), rather than in terms of actual student safety. Another area to be explored is the prohibition of the use of large vans for pupil transportation. It is not clear why vans are judged safe for elderly and handicapped passengers but unsafe for students.

5. The federal regulations governing public transit operation of school bus services are ambiguous and probably not applicable to public transportation in Iowa. The primary reason for UMTA rules (i.e., to ensure that public transit agencies subsidized with public funds do not compete with private school bus operators) apply to few Iowa school districts.

6. In Iowa, improvements in transportation efficiency have been achieved though increasingly stringent requirements for interagency coordination, at both state and local levels. Currently, the only transportation provider not involved in this process is the school district. It is critical to bring school transportation programs into the planning process if the benefits of service coordination are to be achieved.

7. There are other costs that need to be considered in coordination: agency time, change of procedures, public reactions, union rules and reactions, and unemployment costs.

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Use of Future Scenarios in Long-Range Public Transportation Planning

G. SCOTT RUTHERFORD AND JACK LATTEMANN

The Municipality of Metropolitan Seattle (METRO) needed to update its current long-range plan. Based on experience with the current plan, a new approach was adopted to enhance the agency's ability to respond to alternative futures. Alternative future scenarios for 1987 through 2000 were developed with the help of an expert panel representing diverse but appropriate disciplines. The panel focused on three reasonable scenarios and two others that represented the upper and lower bounds for contingency planning. Implementation of public transportation planning is discussed and key regional factors that require monitoring are identified.

The Municipality of Metropolitan Seattle (METRO), the agency responsible for public transportation in King County, Washington, developed its present long-range plan in the late 1970s, a period which saw two severe gasoline crises and a rapid annual increase in the demand for public transportation services. These crises had a noticeable but short-lived impact on auto travel, and a more lasting impact on political support for alternatives to the automobile, such as public transit.

Expanding federal capital and operating assistance, combined with a strong local funding base and severe equipment shortages during the second gasoline shortage, encouraged METRO to increase service rapidly and embark on an ambitious capital program. METRO's long-range plan, called the 1990 Plan, reflected the optimism about the prospects for public transportation in presenting a detailed list of transit capital and operating improvements in the Seattle metropolitan area. Based on a target ridership forecast of 120 million in 1990, the 1990 Plan was essentially a blueprint for a single scenario of conditions expected to occur during the 1980s, as follows:

- presence of auto disincentives,
- rising gasoline prices,
- increased concentration of population and employment, and
- transit incentives in the form of expanded transit service with lower fares.

In retrospect, METRO exerted direct control over only the last condition, transit incentives. During the 1980s, METRO has embarked on the construction of a downtown bus tunnel to address the problem of transit congestion in downtown Seattle. Transit centers and a large number of park-and-ride lots have been built, and a modern fleet of buses, including the largest number of articulated buses in North America, have provided expanded service, particularly during peak periods.

Despite these accomplishments, transit ridership stopped growing in the 1980s and stood at 63.2 million in 1986. The other conditions on which the 1990 Plan depended have not occurred as anticipated. Disincentives to automobile use have been imposed in a limited number of areas by only a few jurisdictions. The 1990 Plan had assumed that real gasoline prices would increase 85 percent between 1978 and 1990, whereas real prices actually declined in the 1980s. Population and employment growth have occurred largely in low density suburban areas of King County that cannot be served cost effectively with traditional fixed-route transit service.

The shortcomings of the blueprint approach to long-range planning have been pointed out previously in articles by Westerman (*1*) and by Schofer and Stopher (*2*) who emphasize that the central concern of long-range planning is uncertainty. Traditional long-range transportation plans have attempted to deal with uncertainty by eliminating it through a single set of assumptions about the future. Such a blueprint plan is particularly vulnerable to changing conditions that can undermine the assumptions of the plan. A long-range plan may then be no plan at all, as ad hoc decision-making takes over.

METRO'S YEAR 2000 LONG-RANGE PLAN

In July 1986, METRO staff began work on a new approach to guide the long-range plan for public transportation in King County through the 1990s to 2000. In contrast to the 1990 Plan, the new approach calls for the formulation of a number of alternative future scenarios. Each scenario is a hypothetical sequence of events constructed to assess the boundaries of possible future conditions as well as their impacts.

The usefulness of scenarios in exploring the future has been pointed out by futures researchers such as Amara and Wilson (*3*). Scenarios can help policy makers identify choices, understand the factors influencing future conditions, and assess risks and tradeoffs. Scenarios cannot eliminate uncertainty about the future, but they can help planners and decision makers manage uncertainty by increasing initiative while reducing surprise to a minimum.

Although using scenarios in long-range planning is a new approach for METRO, the scenarios approach has been used frequently in the recent past in both public and private sector long-range planning efforts. In the Pacific Northwest, the Northwest Power Planning Council has developed four regional

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G. S. Rutherford, Washington State Transportation Center (TRAC), 135 More Hall, FX-10, University of Washington, Seattle, WA 98195. J. Lattemann, Municipality of Metropolitan Seattle (METRO), Seattle, WA.

economic and demographic scenarios to guide its most recent 20-year electric power and conservation plan (*4*). Sullivan (*5*) has pointed out the relevance of the approach for transportation planning. Recent examples include the Southeastern Wisconsin Regional Planning Commission's alternatives analysis of bus and rail options in the Milwaukee area (*6*) and a study of long-term transportation needs in conjunction with alternative energy scenarios in the Baltimore region (*7, 8*).

Building on this past experience, METRO's new long-range plan will use future scenarios to provide a context for assessing future markets for public transportation in King County, developing assumptions for ridership forecasts, and identifying appropriate mixes of services and facilities best suited to a range of future conditions. The approach will provide a framework for strategic thinking about both threats and opportunities for public transportation in King County through 2000, as well as establish an ongoing process to monitor conditions and offer timely input to the annual budget process.

In contrast to the 1990 Plan, which specified services and facilities needed to meet the demand of a target ridership, the new long-range plan will take into account three scenarios that could affect public transportation in METRO's service area. Potential public transportation markets will be identified for each of these futures. Types of services and facilities, termed public transportation "products," will then be matched to the markets in each scenario.

Sets of products will be organized into four components of the new long-range plan. These components will include the following:

- *Core Program.* This program represents the minimum commitment necessary to maintain the 1990 services and facilities until 2000 and assumes no new or added public transportation programs.
- *Scenario Plans.* Sets of products best suited to the market conditions described in each scenario will be developed into alternative public transportation plans.
- *Basic Program.* This program will include those public transportation products appropriate to all three future scenarios, as well as elements of the Core Program.
- *Implementation Program.* Program priorities for initial implementation will be developed from the Basic Program and the assessment of the direction of current trends.

Figure 1 describes conceptually the development of the long-range plan.

The scenario outlines developed by the expert panel and described below will be expanded into more detailed quantitative and qualitative descriptions. These descriptions will be used in subsequent tasks to guide the assessment of future public transportation markets and products, forecasts of transit ridership under each scenario, financial analyses of alternative plans, and development of an ongoing monitoring program.

The scenario descriptions will be particularly important in transit ridership forecasting and analyzing future markets for public transportation. Quantifiable detail about the concentration and distribution of households and employment will be desirable to analyze changes in land use under each scenario. The analysis of changes in future travel costs and congestion will require assumptions to be made about trends in real household income, private auto ownership and operating costs, and auto parking costs under each scenario. This effort will consider available national and regional studies and data in developing the descriptions.

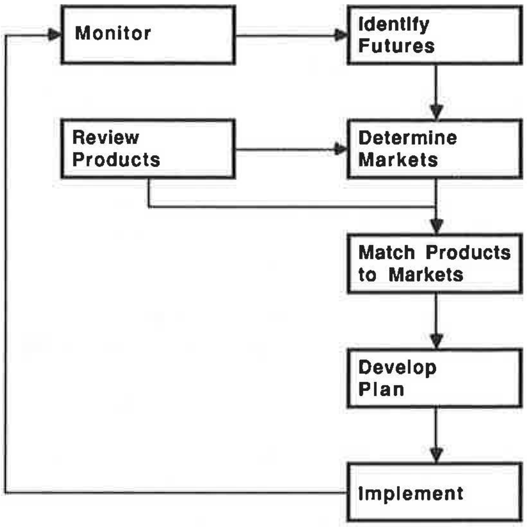

FIGURE 1 Development of the long-range plan.

SCENARIO DEVELOPMENT PROCESS

METRO Futures Team

To further develop the scenario approach and also develop background information, a METRO staff team was formed in September 1986. This interdivisional group, called the Futures Team, began its work by researching other long-range planning efforts around the country and identifying trends and events, external to METRO, that could affect supply of and demand for public transportation. The team identified five general categories of trends and events with the following ranges of variability:

1. Economy and trade

- rapid economic growth
- moderate economic growth
- economic decline

2. Petroleum availability and price

- plentiful supply and no real price increase
- plentiful supply and low price in the early 1990s, shortages and large price increases later in the 1990s
- volatile supply and price
- stable supply and gradual price increases

3. Major directions in public policy

- expanded government intervention and spending
- government deregulation and reduced spending

4. Technological innovation

- rapid rate of innovation
- slow rate of innovation

5. Demographic trends

- increased elderly population, smaller teenage cohort, smaller households, greater number of middle-aged households (common to all scenarios).

Each variable was arrayed against every other variable in the form of a matrix for undertaking a cross-impact analysis. The purpose of analyzing cross-impacts was to assess which variable might do the following:

1. enhance or provoke another variable;
2. inhibit, block or render infeasible or implausible certain other variables; or
3. show little or no relationship with other variables.

An explicit identification of cross-impacts assisted in screening out combinations of variables that are implausible or are not likely to occur at the international, national or regional levels.

The Futures Team then developed 18 combinations of variables using a cross-impact table to represent an entire range of possible conditions. An outline of this table is shown as Figure 2. To simplify the process of developing scenarios, only economy, energy, and public policy variables were subsequently used to form possible combinations. Since the same demographic trends would be present in all combinations, demographics were not used as a variable to define different scenarios. Technological innovation was considered to be secondary in importance to the three variables and was also dropped from consideration.

The cross-impact table was used to narrow the number of preliminary scenarios. Nine scenarios were dropped because they appeared less plausible, highly unlikely or less meaningful in terms of implications for public transportation. The nine remaining scenarios, shown by circled combinations in Figure 3, were submitted to a panel of outside experts for further development.

Expert Panel

A distinguished panel of experts with knowledge of economics, demographics, social sciences, development, law, trade

		IMPACTED VARIABLES									
		ECONOMY			ENERGY			PUBLIC POLICY		TECHN. INNOVATION	
	IMPACTING VARIABLES: Effect of this range on →	(1) Rapid Economic Growth	(2) Moderate Economic Growth	(3) Economic Decline	(1) Plentiful Supply Constant (low) Price	(2) Volatile Supply and Price	(3) Stable Supply Gradual Price Increase	(1) Expanded Govt. Intervention & Spending	(2) Govt. Dereg. & Reduced Spending	(1) Rapid Rate of Innovation	(2) Slow Rate of Innovation
ECONOMY	(1) Rapid Economic Growth										
	(2) Moderate Economic Growth										
	(3) Economic Decline										
ENERGY	(1) Plentiful Supply Constant (low) Price										
	(2) Volatile Supply and Price										
	(3) Stable Supply Gradual Price Increase										
PUBLIC POLICY	(1) Expanded Govt. Intervention & Spending										
	(2) Govt. Dereg.and Reduced Spending										
TECHN. INNOVATION	(1) Rapid Rate of Innovation										
	(2) Slow Rate of Innovation										
DEMOGRAPHICS	Demographic profile characterized by: • Increased elderly population • Smaller teenage cohort except for minorities • Smaller households • Increase in middle-aged households										

FIGURE 2 Cross-impact analysis of independent scenario variables.

POLICY TREND: Expansion in government expenditures; emphasis on regulation and government intervention		ECONOMY		
		(1) Rapid economic growth	(2) Moderate economic growth	(3) Economic decline
ENERGY	(1) No real price increase	Ⓐ	Ⓑ	C
	(2) Plentiful supply and low price untril early 1990's shortages and large price increases in the late 1990's	D	Ⓔ	Ⓕ
	(3) Stable supply and gradual real price increase	G	H	I

POLICY TREND: Contraction in government expenditures; emphasis on deregulation		ECONOMY		
		(1) Rapid economic growth	(2) Moderate economic growth	(3) Economic decline
ENERGY	(1) No real price increase	Ⓙ	Ⓚ	L
	(2) Plentiful supply and low price until early 1990's shortages and large price increases in the late 1990's	M	Ⓝ	Ⓞ
	(3) Stable supply and gradual real price increase	P	Ⓠ	R

FIGURE 3 Preliminary scenario matrix.

and business was assembled. The purpose of the panel was threefold: to provide technical expertise on national and regional trends and issues, to independently review and validate the scenarios developed by staff, and to reach a consensus on three scenarios to be used in developing METRO's Long-Range Plan. Panelists were not asked to develop policy responses to future conditions, assign probabilities or values to particular regional scenarios, reach a consensus on one scenario, or attempt to estimate impacts of various scenarios on specific jurisdictions.

The composition of the METRO scenarios panel differed from panels of other scenario development efforts in that METRO's panelists were neither asked nor expected to render policy judgments. This objective differs from other scenario development efforts such as the Baltimore study (*7*), where a group of regional officials was assembled to consider public policy responses to alternative energy scenarios.

The panel members included the following disciplines and expertise:

- a bank economist,
- a professor of geography,
- a vice president of a development company,
- a law partner and trade expert,
- a professor of public affairs,
- a professor of economics, and
- a director of market research for a large manufacturing company.

The panel members met in three sessions over a two-month period to develop a set of scenarios that reflected what could reasonably happen before the year 2000. Considerable time was spent discussing alternative directions for the local economy in conjunction with linkages to the national economy and international trade. The panel recognized that regional economic cycles have swung higher or lower than national economic cycles. This variability was attributed to the region's dependence on a single employer, the Boeing Company.

In the late 1960s, a boom in aerospace employment was followed by a bust, thrusting the four-county central Puget Sound region into an economic depression as Boeing employment fell from 120,000 in 1968 to 40,000 jobs by 1971. Although the region's economy has diversified since then, particularly in King County, Boeing remains the single most important employer, with 86,000 jobs in the region as of early 1987 and 70,000 jobs in King County alone. Boeing employment comprises a smaller percentage of total county employment than in the late 1960s, but the value of output has remained close to 20 percent of regional output (*9*). The history of economic expansion and contraction led the panel to pay specific attention to alternative directions of the aerospace sector in King County.

Because METRO staff supplied the panel with nine preliminary scenarios well in advance of the first panel session and offered strong support throughout the panel process, the panelists were already familiar by the first session with the format of the scenarios and the objectives of the process. One major change made by the panel to the work done by METRO staff was to redefine the public policy variable. The panel saw the federal budget deficit as an issue of paramount importance, and therefore did not see a significant expansion in real terms of federal spending as a realistic option. Consequently, the panel redefined the national policy variable around the distribution of spending between military and non-military programs and around deregulation versus policy intervention.

The aforementioned considerations and other discussion led to respecification of the scenarios in the form of an intermediate matrix, as shown in Figure 4. Dimensions of change in economic and energy variables were quantified into rates of economic growth or decline and real percentage change in energy prices.

Other key points made during the sessions that influenced the description of the scenarios eventually chosen by the panel are summarized below:

- Puget Sound has an economic cycle different from that of the U.S. and the rest of the state due to the impact of Boeing's aerospace employment and the ports of Seattle and Tacoma.
- Federal expenditures may shift in emphasis from military programs to social and infrastructure programs but will not decline in absolute level.
- The Boeing employment trend looks strong due to the favorable prospects for the aircraft replacement market in the 1990s.
- Per capita income should increase as the baby boom generation ages.
- Downtown Seattle has developed rapidly as a regional finance and trade center.
- Energy prices should rise gradually during the 1990s.

POLICY TREND:

Federal government expenditures increase at rates slightly higher than inflation; more domestic policy intervention and expenditures shifted from military to domestic issues

		KING CO. ECONOMY			
		(1) Rapid growth, 3+%	(2) Moderate growth, 1 – 3%	(3) Steady growth, 0 – 1%	(4) Decline 0 to -2%
ENERGY	(1) No real price increase	Ⓐ	Ⓑ	C	D
	(2) Price increase 50% higher than rate of inflation	E	F	Ⓖ	H
	(3) Price increase twice rate of inflation	I	J	Ⓚ	L

POLICY TREND:

Reduction in increase of federal government expenditures; continued emphasis on deregulation and military expenditures

		KING CO. ECONOMY			
		(1) Rapid growth, 3+%	(2) Moderate growth, 1 – 3%	(3) Steady growth, 0 – 1%	(4) Decline 0 to -2%
ENERGY	(1) No real price increase	Ⓜ	Ⓝ	O	P
	(2) Price increase 50% higher than rate of inflation	Q	Ⓡ	S	T
	(3) Price increase twice rate of inflation	U	V	W	Ⓧ

FIGURE 4 Intermediate scenario matrix.

- The female labor force participation rate is flattening due to lack of affordable child care and slower growth in service sector jobs.
- Reduced military expenditures will not have a dramatic effect on King County, since major military installations are located in other counties.
- Local jurisdictions outside Seattle will continue to attract high technology firms and business service development.
- Puget Sound is in an excellent geographic position to benefit from the growth of trade with Asian countries.
- Increased efficiency in railroad operations will benefit distribution activities related to international trade.
- Alaska's recent economic downturn will not have a big effect on King County since it affects only 2 to 3 percent of Puget Sound's economy.
- No new transportation technology is likely to be commercially available before the year 2000 because of the long lead times necessary to introduce innovations.
- Federal taxes will likely be increased to cover the budget deficit.
- Household income is rising due to female labor participation and non-wage income.
- Trade protectionism will have short-term impacts only since the U.S. depends on trade.
- Boeing is diversifying; 40 percent of its business is now the manufacture of commercial airplanes.
- Development will push to outlying areas because of cheaper land farther out and attempts to regulate growth.
- Lack of uniform government policies on growth in King and adjacent counties is a deterrent to more concentrated development patterns.

Scenario Selection

Panel members considered all possible matrix combinations shown in Figure 4, and narrowed their attention to the eight circled intermediate scenarios by the end of the second panel session. Through discussion and debate, the panel at its third session recommended three primary scenarios for use in developing METRO's long-range plan for the 1990s. Two additional scenarios were identified to reflect extreme conditions with a low probability of occurrence; these extreme scenarios can be used in contingency planning.

Figure 5 shows the five scenarios selected by the panel. The King County environment under each scenario was described in terms of the following characteristics:

- *National Policy Trend*: The balance between military and social programs at the federal level, and the degree of emphasis on government deregulation versus government intervention.
- *Demographic*: Regional demographic trends.
- *Economic*: Production, distribution, and consumption of goods and services at the international, national, and regional levels.
- *Employment*: Job composition and unemployment rates.
- *Housing and Land Use*: Residential and employment composition, spatial distribution, and housing demand.
- *Energy*: Price and availability of gasoline and other energy resources.
- *Institutions*: Land use regulation and policy, relations between state and local governments, and state and local taxation.

Planning Scenarios

In Figure 5 Scenarios B, R/N, and G/K represent the panel's consensus on a range of scenarios to cover the period from now to 2000. Detailed descriptions of these scenarios follow:

Scenario B—Prosperity Continues An overview of Scenario B is shown in Figure 6. At the national level, this scenario assumes a slightly more liberal administration and Congress, which would shift some military spending to non-military programs. New tax revenues would be raised to reduce the federal budget deficit. More domestic policy intervention is also assumed; this might mean an increase in federal assistance for public transportation. "Free trade" policies nationally would be conducive to a rapid expansion of trade through the Port of Seattle.

The Puget Sound economy would remain strong, as it is

Metro Year 2000 Scenarios Long Range Plan Update		KING CO. ECONOMY			
		(1) Rapid growth, 3+%	(2) Moderate growth, 1 – 3%	(3) Steady growth, 0 – 1%	(4) Decline 0 to -2%
ENERGY	(1) Price increase 0-25% greater than inflation	M	B		
	(2) Price increase 25-75% greater than inflation		R/N	G/K	
	(3) Price increase 75% greater than inflation				X

FIGURE 5 Final scenario matrix.

KING COUNTY ENVIRONMENT

National Policy Trend	Federal government expenditures increase at rates slightly higher than inflation; more domestic policy intervention and expenditures shifted from military to domestic issues
Demographic	In-migration 1-2% Real wages stable
Economic	Redistribution of jobs from military to domestic issues Rapid port growth 4% Boeing employment 90,000 in 2000 Reduced military contracts Overseas aviation competition reduced R&D investment increases Manufacturing grows slightly Retail/commercial expansion
Employment	Aerospace grows High tech shows rapid rise (small base) Unemployment at or slightly lower than U.S.
Housing & Land Use	Continued suburban growth Dispersion of employment
Energy	Little interest in conservation No increase in real gas price
Institutions	Local role and taxes increase Gas tax increases Growth controls spread sprawl further out Little cooperation between local government and developers

FIGURE 6 Scenario B—prosperity continues.

currently. This economic growth, led by Boeing and the ports, would cause expansion in nearly all economic sectors. Employment in downtown Seattle would continue to increase, while dispersed housing and commercial expansion would continue in the suburbs. Due to continued low fuel prices, little interest would be shown in conservation efforts.

Low interest rates and growth in per capita income would result in a strong housing market, particularly in the early 1990s. Low gasoline prices and the continuing demand for road improvements would result in passage of an increased state gas tax. Local jurisdictions would compete with one another for both new development and state funds for infrastructure improvements.

In summary, this scenario is basically an improvement on the economic and social conditions experienced by the central Puget Sound region during the mid-1980s.

Scenario R/N—Business As Usual This scenario outline is shown in Figure 7. At the national level, the emphasis on deregulation and control over the federal budget deficit would continue. Military expenditures for research and development would remain constant, thereby helping high tech firms in the region. A reduction in the growth of federal expenditures would occur, and this would sustain current trends in federal financing of public transportation.

By the late 1990s, higher energy costs would dampen the economy, and overall economic activity would grow at a rate lower than that in Scenario B. Boeing employment would remain steady.

Downtown Seattle and suburban areas would continue to grow. The dispersed nature of suburban development would make traditional transit service difficult to provide cost-effectively.

Owing to a rise in energy prices and the slow growth of the state's economy, gas taxes would not be increased. Local jurisdictions would be forced to seek agreements with the private sector to share in the cost of road improvements.

In summary, this scenario represents a continuation of present trends in King County.

Scenario G/K—Slowdown Figure 8 provides a summary of Scenario G/K, which takes place in the context of national policies similar to those of Scenario B, except for increased protectionism. Scenario G/K is characterized by slower growth in the regional labor force and productivity. Higher interest rates and higher inflation would adversely affect economic sectors associated with durable goods and capital investment. This scenario assumes that the balance of trade deficit and federal budget deficit would remain serious problems into the 1990s. The political results would be protectionism and new federal taxes by the late 1990s.

Higher energy prices, a downturn in Boeing employment, and lower port activity would cause the entire local economy to slow. In-migration would be reduced, unemployment would be up, and business activity would be flat.

Energy conservation efforts would make a comeback due to high energy prices and a major supply interruption in the early 1990s. Lower household incomes and higher fuel prices would push people to alternative modes of transportation.

Office development in downtown Seattle would slow as vacancy rates rose. Suburban growth would also slow. Tax increases would be modest due to economic conditions.

KING COUNTY ENVIRONMENT

National Policy Trend	Reduction in increase of federal government expenditures; continued emphasis on deregulation; military expenditures constant in real terms
Demographic	In-migration 1-2% Real wages stable
Economic	Moderate port growth (2% average annual growth) Boeing employment 80,000 in 2000 Steady military contracts Increased overseas aviation competition R&D investments increase Manufacturing moderate Retail/commercial expansion
Employment	Aerospace stable High tech shows rapid rise (small base) Unemployment matches U.S.
Housing & Land Use	Continued suburban growth Dispersion of employment
Energy	Some interest in conservation Gas prices increase 50% higher than inflation
Institutions	Local role and taxes increase No gas tax increase Growth controls spread sprawl farther out Little cooperation between local government and developers

FIGURE 7 **Scenario R/N—business as usual.**

In summary, protectionism and higher energy costs would affect King County through higher unemployment and slower economic growth.

Contingency Scenarios

Scenarios B, R/N, and G/K described above will be used as the primary alternatives for the development of METRO's new long-range plan. The panel also selected two contingency scenarios, which will provide the outside boundaries on the conditions which could result if a rather remote combination of events occurred simultaneously. These scenarios are useful to answer "what if" questions but are not probable enough to justify the development of major plans to respond to them. However, the testing of final planning alternatives against these scenarios could provide the necessary information to develop contingency plans.

KING COUNTY ENVIRONMENT

National Policy Trend	Federal government expenditures increase at rates slightly higher than inflation; more domestic policy intervention and expenditures shifted from military to domestic issues
Demographic	No in-migration Real wages decline slightly
Economic	Moderate port growth at current annual rate Boeing employment 70,000 in 2000 Reduced military contracts Slow increase in overseas aviation competition R&D investment flat Small manufacturing flat Retail/commercial flat
Employment	Aerospace shows decline High tech steady Unemployment at or slightly higher than U.S. Other sectors stable
Housing & Land Use	Slowed suburban growth New employment dispersed
Energy	Some conservation efforts Gas prices increase 75% higher than inflation One major supply interruption
Institutions	Local tax increases moderate No gas tax increases

FIGURE 8 **Scenario G/K—slowdown.**

The two contingency scenarios below were selected by the panel. One describes conditions for extremely rapid regional economic growth and the other a prolonged regional recession.

Scenario M—Regional Boom This scenario, shown in Figure 9, takes place in the context of conservative national policies, few restrictions on trade, and a booming economy in the central Puget Sound region. Rapid economic growth in all sectors would be fueled by high Boeing employment and an expansion of trade through the ports of Seattle and Tacoma.

Owing to rapid economic growth, the region would experience high levels of in-migration and increases in real per capita income. Unemployment would be less than the U.S. average and labor shortages would appear in the service industries. Although downtown Seattle would expand rapidly in employment, the predominant trend would be explosive growth of low-density commercial and residential development outside the city of Seattle, particularly in unincorporated King County. Rapid suburban employment growth, combined with low interest rates and growth in per capita income, would result in a strong housing market.

Since gas prices would remain low, there would be little interest in conservation. Low gasoline prices and the demand for road improvements would result in passage of an increased state gas tax in the early 1990s to fund both road and public transportation improvements. Local jurisdictions would compete against one another for both new development and funds for infrastructure improvements.

In summary, this scenario assumes an extraordinary period of economic growth, resulting in rapid urban and suburban development. Severe congestion problems in the region's transportation system are a consequence of such rapid growth.

Scenario X—Prolonged Recession Scenario X, shown in Figure 10, would occur in the context of a prolonged decline in the national economy and protectionist trade policies. This decline would affect the central Puget Sound region more severely than the U.S. due to substantial reductions in port activity and a massive Boeing employment reduction, causing out-migration, particularly in aerospace and other high tech industries.

Past over-expansion of retail, commercial and residential development would cause business failures and banking problems. Unemployment would be much higher than the U.S. average. Higher interest rates and higher inflation would depress the economic sectors associated with durable goods and capital investment.

Several major interruptions in petroleum supplies are assumed to occur in the late 1990s, followed by significant

KING COUNTY ENVIRONMENT

National Policy Trend	• Reduction in increase of federal government expenditures; continued emphasis on deregulation; military expenditures constant in real terms
Demographic	• High in-migration in all employment sectors • Real wages increase
Economic	• Port expands rapidly due to reduced controls (free trade) • Boeing employment 100,000 in 2000 • Massive military contracts • Overseas aerospace market share increases for Boeing to 60% • Other sectors expand rapidly • State's economy expands with timber, agricultural and minerals
Employment	• Aerospace booms • High tech shows very rapid rise • Unemployment 1% less than U.S. • Manufacturing increases • Retail/commercial rapid rise • Service employment labor shortage • Other sectors expand rapidly
Housing & Land Use	• Explosive suburban growth • Cross-lake traffic expands eastside development (housing and commercial) • Infill in Seattle increases • Apartment complexes multiply in suburbs • Housing costs and rents rise rapidly
Energy	• No interest in conservation • No real price increase
Institutions	• Local tax increases • Gas tax increases steadily to build roads and fund transit improvements • Many conflicts between developers and suburban governments • Near-in suburban growth controls create sprawl in fringe

FIGURE 9 Scenario M—regional boom.

KING COUNTY ENVIRONMENT

National Policy Trend	Reduction in increase of federal government expenditures; continued emphasis on deregulation; military expenditures constant in real terms
Demographic	Out-migration, particularly in aerospace Real wages decline
Economic	Port declines rapidly Boeing employment 45,000 in 2000 Military contracts cushion Boeing from further decline High tech bust with no investment All other sectors in rapid decline after 1995 Local mortgage banks fail Retail bust due to overexpansion
Employment	Aerospace shows rapid decline High tech in rapid decline Unemployment 6% over U.S. Military manpower constant
Housing & Land Use	No growth, development stops Many vacancies and houses for sale
Energy	Price increase at twice inflation rate One or more supply interruptions OPEC price rise throughout decade Much conservation due to poor economy and reduced travel for employment and other trips
Institutions	Public works programs begin mid-decade State tax base shrinks, causing institutional conflicts

FIGURE 10 Scenario X—prolonged recession.

increases in petroleum and natural gas prices. Energy prices, which would increase at twice the inflation rate, would reduce travel and put pressure on public transportation systems. Institutional conflicts would result from a shrinking tax base and demands for social services. Development would essentially stop due to previous over-expansion.

Summarizing, the scenario includes the impact of downturns in the region's two most important industries, aerospace and trade. Their employment base has a very large impact on the local economy. Some eastern U.S. cities have experienced similar conditions when their basic industries have declined.

Scenarios Versus Snapshots

Our national and regional economies experience many cycles during a period longer than a decade. The scenarios discussed here are meant to reflect a long-term trend rather than snapshots of conditions in any given year. Public transit decisions are made both in the short and long run and the planning processes must respond to various time periods. The next section will outline some of the implications of using these scenarios in the planning process.

PLANNING IMPLICATIONS OF SCENARIOS

Planning Scenarios (Scenarios B, R/N and G/K)

The planning scenarios can help provide basic information for developing necessary forecasts, public transportation alternatives, and policies. The parameters of the scenarios are generally out of METRO's control or influence (employment, gas price, etc.) but define the information for input to the planning process. The following paragraphs will outline the major differences in the three planning scenarios and discuss their implications for the planning process. The national policy trend impacts are assumed to be translated into local effects and will not be discussed individually.

Scenario B—Prosperity Continues

This scenario assumes continued strong growth of the local economy and sustained development activity. Downtown Seattle would continue to develop as a financial center and congestion in corridors would increase dramatically. Suburban growth would be dispersed for residential and commercial development. Because of the growth, regional travel forecasts would be increased substantially. While the density increase in downtown Seattle would benefit transit, many of the new jobs would be in higher income groups and might need special services to attract them to public transportation. Subscription buses, well-equipped vans, rail service, or additional high-quality express bus services might be necessary. Given the projected congestion levels this scenario could be an excellent opportunity for such services.

Serving the suburban growth would be more problematic. This scenario is a strong argument for land use planning at the county level to provide more concentrated employment centers served by nearby residential areas and to coordinate commercial development with highways and public transportation. METRO's current services would have to be expanded greatly in the non-bus modes (carpools and vanpools). This scenario would include tax increases that could support additional capital and operating expenditures for highways and public transportation. Pressure for high-capacity transit facilities in major corridors would increase.

Scenario R/N—Business As Usual

This scenario assumes less economic growth than Scenario B and higher fuel costs. This lower growth would still result in an increase in travel and congestion. However, higher fuel prices would make public transportation more competitive. The opportunities for the Seattle downtown and suburbs discussed in Scenario B would still apply here, but the higher fuel prices would increase the use of the services described. While the panel did not make a formal selection, it favored this scenario as the most probable.

Scenario G/K—Slowdown

Scenario G/K assumes a much lower rate of economic development and sharply higher fuel prices with a major fuel supply interruption. While employment growth would be reduced, the high fuel prices and continued congestion would make public transportation attractive. However, pressure for increased public transportation services would be difficult to respond to owing to limited tax resources. Under this scenario there would be much less likelihood that sufficient tax resources would be made available to construct high-capacity transit facilities.

Contingency Scenarios (Scenarios M and X)

Scenario M—Regional Boom

The congestion caused by low fuel prices and unprecedented growth would probably lead to capital investments for high capacity public transportation and new arterials and highways in the suburbs. Given the lead time for capital projects, it is unlikely that many of these facilities would be in place before 2000. Expansion of existing modes would provide additional capacity. However, construction projects in present freeways and roads would degrade the service quality of bus routes operating in these corridors. Suburban congestion would get much worse; however, as in other high growth counties in the U.S., the expansion would continue.

Scenario X—Prolonged Recession

In this scenario, fuel prices rising at twice the rate of inflation would make public transportation attractive to the people who still had jobs or money to spend. There would be no major capital transportation projects unless they were linked to public works programs. Current public transportation modes would likely be operated near capacity.

NEXT STEPS

Development of Detailed Scenario Descriptions

More detailed scenario descriptions are being developed from the outline of the five scenarios recommended by the panel. These descriptions will be divided into two periods, early 1990s and late 1990s. Details will focus on King County conditions and be summarized into four categories directly relevant to public transportation. These categories are Economy, Energy, Housing and Land Use, and Policy Trends and Institutions.

Quantitative dimensions will be included in the detailed descriptions as key inputs to the transit and ridesharing forecasting processes. These inputs include the following:

- population and employment distribution,
- household income,
- parking charges, and
- auto operating and ownership costs.

As part of plan development, different combinations of inputs under each scenario will be tested using the EMME2 software package and an elasticity-based forecasting methodology. Qualitative elements of the descriptions will be used to recommend major program directions and priorities within the long-range plan.

Monitoring Process

METRO has already instituted a process to assess market strategy in advance of the annual budget review. A market strategy report is produced that reflects decisions on priorities for programs and projects. One task in the development of this report is an environmental scan with a five-year time horizon.

The monitoring process proposed for METRO's new long-range plan fits very well with the annual market strategy assessment. Monitoring is an essential element of the future scenarios approach, in that it will allow the organization to respond better to changing conditions, many of which are beyond its control. Information about regional conditions will help METRO gauge how well its long-range plan is matching the assumptions under which the plan was developed.

Every two to three years, a special effort would be made to reevaluate the set of future scenarios upon which the long-range plan is based. New medium- (five years) and long-range (ten years) transit ridership forecasts could be prepared. For the purpose of setting priorities, a five-year time horizon would be more useful than ten years in most cases.

A preliminary list of key external indicators to monitor has been identified. This list will be revised as METRO develops its long-range plan and gains experience with the annual process. This list includes the following:

1. Demographics

- household size and income
- population distribution

2. Economy

- general distribution of employment
- Boeing employment level and distribution
- trade volume through the Port of Seattle
- automobile ownership and operating cost

3. Housing and Land Use

- office vacancy rates
- employer size
- interest rates
- building permits
- parking cost in downtown Seattle and other activity centers

4. Energy

- gas price
- auto fuel consumption

In addition to the preceding external factors, internal performance measures will also be incorporated in the monitoring process.

CONCLUSION

The future scenarios approach represents a departure from previous long-range planning at METRO. By incorporating an annual monitoring process, the scenarios approach holds promise of overcoming the static nature of previous long-range plans.

One criticism that can be raised about the scenarios approach is that it may encourage a "wait and see" posture on the part of both planners and decision makers, especially when they are faced with a decision about a major capital investment project with a long lead time. However, the establishment of the justification for a proposed major project under multiple scenarios might actually increase the decision makers' confidence level and persuade them to move ahead with the project.

The benefits of the scenarios approach—the identification of choices, increased understanding of factors influencing those choices, and the assessment of risks and tradeoffs—present strong reasons for proceeding in a new direction for long-range planning. The results of this approach will be evaluated and compared with previous long-range planning efforts.

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Practical Approach for Solving School Bus Problems

HUEL-SHENG TSAY AND JON D. FRICKER

Most of the numerous studies of school bus routing seem to possess two basic characteristics: ever-increasing sophistication of computer-based routing algorithms and neglect of the service side of the problem. While reducing the total cost of providing transportation services to students is important, so are such elements as student walking distance and bus load factors. In this paper a multi-objective view of school bus problem is formulated, and a three-stage simplified solution process is outlined and demonstrated. The advantages of using goal programming to solve this multi-objective problem are discussed. Then, a comparison of the proposed algorithm with the previously developed approaches is presented. Finally, a case study of 21 bus stops covering 270 student homes and 5 buses available is discussed in terms of the proposed solution.

Studies of the school bus routing problem are numerous. Krolak and Williams (*1*) provide a good summary of the basic approaches in this field. Most of these studies have considered standards for quality of service, such as a student's maximum in-bus travel time. What is usually overlooked as a service variable in transporting school students is the walking distance from home to the school bus stop. The typical routing study accepts bus stop locations as given, and proceeds to develop efficient routing algorithms. The school bus administrator and the operations he/she oversees would benefit from an unpretentious method to establish and evaluate bus stop locations, in accordance with a set of service criteria or school policies. This paper outlines such a method.

Tsay (*2*) and Fricker (*3*) examined the bus stop and location aspects of the problem in some detail. Among their findings were the following factors:

1. School bus stops are not systematically located to assure that a maximum walk distance standard for students is satisfied.
2. Techniques such as Facility Location Algorithms (*4–8*) can provide improved service to students, in terms of reducing walk distances from home to bus stop.
3. The Facility Location Algorithms that accomplish these improvements tend to be complex to formulate and encode for computer processing.
4. Minimizing the number of bus stops in an area does not necessarily improve the results of the subsequent routing algorithm.

Bodin and Berman (*9*) and Desrosiers et al. (*10*) are among the few to have acknowledged the existence of students' residential locations. In both studies, students were assigned to "mini-stops" at a street intersection at one end of their residential block. The mini-stops were then either assigned to prescribed stops or grouped at intersections to form new bus stops. Neither reference gave details of the computer program used to implement the scheme or the resulting walking access distances.

Based on these experiences, an algorithm that incorporates basic service aspects of school busing, while striking a balance between effective optimization techniques and ease of understanding and implementation, is presented in this paper. it shows a series of steps, accompanied by an example that addresses the school busing problem in a manner that extends beyond pure routing. This paper presumes a knowledge of basic optimization techniques. The process does not require mastery of abstract or complex mathematical derivations, and will not require extensive computer programming effort. The mathematical formulations and notation that will be employed are mainly to aid the user in matching the problem to a typical computer routine's documentation.

SPECIFYING GOALS IN SCHOOL BUSING

Before undertaking any modeling, the major goals have to be specified in school busing. The setting of goals is an art. Their values should not be unreasonably high or low, if achieving (rather than merely approximating) these goals is desirable. In fact, regardless of the particular structure of the solution process, the goals of the school bus service can remain the same. The six major goals adopted in this paper are as follows:

1. Limit maximum walking distance from a student's home to his/her assigned bus stop to one-third mile or less.
2. Guarantee each eligible student transportation to school.
3. Avoid underuse of equipment; balance school bus load factors.
4. Avoid circuitous routes and hazardous zones.
5. Avoid overcrowding in each bus.
6. Minimize the total transportation cost of providing service.

One-third mile is specified as the maximum walking distance in the first goal. This value can be changed, depending upon the characteristics and philosophy of the school district. Obviously, setting different constraints on maximum walking

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H.-S. Tsay, Graduate School of Transportation and Communication Management Science, National Cheng Kung University, Taiwan, Republic of China. J.D. Fricker, School of Civil Engineering, Purdue University, West Lafayette, Ind. 47907.

distance can result in different solutions for the optimal school bus routes. The same can be said for changes made in the values of the standards developed for any other goals.

It is likely that not all of these six goals can be met simultaneously. The school bus administrator should be allowed to rank his/her goals in order of importance. Although this task may be made unpleasant by conflicting interests, its accomplishment leads systematically to the kind of bus service desired. Traditional routing schemes (*1*) can be modified to include most of the goals listed above, but those schemes are not sensitive to the goals' relative importance. These schemes invariably have "minimize total transportation cost or distance" as an objective function, and express the other goals as constraint equations, if possible. Each of their traditional "goal-constraints" has a single limiting value that helps to determine the feasibility of the solution routes and carries the same relative weight as the others. This paper presents a process that allows more flexibility in designing school bus service. The steps that include ranked goals in the complete process are described and demonstrated in the next section.

STEPS IN THE SCHOOL BUS ROUTING SOLUTION

Step 1—Establish Subdistricts

Seldom does there exist a school district so devoid of topographical barriers, municipal boundaries, or directional orientation of road network, that "natural" subdistricts do not emerge. The procedures presented here confine themselves to computer routines that are relatively inexpensive to run, but there is no reason to run a large problem, when running a series of small subproblems gives similar results with noticeable cost savings and increases in administrative control. The cost savings arise because many computer programs for this type of problem do not simply double in cost of execution as problem size doubles: these costs can increase exponentially. Decomposing the problem into manageable parts may achieve significant savings in total cost without loss of a valid solution. The school district in Fricker's study (*3*) contained more than 2400 students, covered 50 square miles, and involved wide variations in population density and road network configuration. These variations gave strong indications where subdistrict boundaries should be.

It is advantageous, however, to keep each subdistrict large enough to allow several buses to seek their best routes within its boundaries. Once the stops and routes are established, subdistricts can be combined to allow reevaluation or student assignments for better use of bus capacity and greater flexibility in routing.

Step 2—Locate Student Homes on a Map

This is always a tedious, time-consuming step, especially the first time. But avoiding excessive walk distance between home and bus stop makes this a necessary and justifiable step. Most school districts do this already. The method used in this paper does not require that a school district's entire road network be coded for computer analysis. This is discussed further in the following section. The study area for the sample problem, with the locations of student's homes, is shown in Figure 1. Each dot point represents the location of a student residence along a street link. There are 270 students in area shown in Figure 1.

Step 3—Locate Bus Stop Zones

As mentioned earlier, Tsay and Fricker studied relatively expensive Facility Location Problem routines, designed to solve the General Absolute Facility Location Problem (*11, 2, 5, 8*). Fricker's approach, and those of Bodin and Berman (*9*) and Clarke and Wright (*12*), involves creating a data file containing the length, location, and student population of each street link in a subdistrict. While not yet economical as a direct aid to a school district, the study did offer some useful lessons. Besides those lessons listed earlier, it was found that siting bus stops in densely populated urban areas (such as in the lower left portion of Figure 1) was not governed by any reasonable access distance (such as one-third mile), but rather by the number of students assigned to their nearest stop. For certain stops in an urbanized subdistrict, this number can exceed the capacity of a school bus. More than one bus could be assigned to those stops, or the stops could be increased in number and moved closer together, thereby permitting very short walk distances.

In sparse rural areas and at small settlements (the upper half of Figure 1), bus stop siting was obvious: at the isolated student's driveway and at the center of a settlement. It was in medium-density settings that a systematized procedure seemed most necessary. At the outskirts of cities and in subdivisions, a large number of reasonable bus stop site combinations are possible. A simple and low-cost way to establish and visually evaluate alternative combinations involves the use of templates.

Figure 1 shows a scale of 150 mm = 1 mile. The maximum walking distance of one-third mile then equates to a map distance of 50 mm. Geometric shapes or templates (Figure 2) can be constructed to cover parts of a subdistrict so that no point is farther away than 50 mm from the predetermined bus stop within a shape, using the existing street network. A bus stop placed on any trafficable street within that "covered" area will be within 50 mm of all student homes covered. A suitable objective for the user is to cover as many student homes as possible with the application of a template. If there exist hazardous zones that students should not cross, Figure 1 can be marked first to show these dangerous streets and then applied the templates to determine the suitable bus stops. In addition, the bus stop can be suitably adjusted if the predetermined bus stop is not appropriate in the initial assignment. The few questionable cases caused by unusual street patterns can be checked individually.

In grid street networks, the natural geometric choice is the family of rectangles whose length plus width equals 50 mm, as shown in Figure 2. The templates could be enlarged to almost twice this size and bus stops placed near their centroids, but the 50 mm size offers more flexibility. Other geometric shapes, such as circles, can be constructed if the nature of the street network makes them more useful than rectangles. For example, if it were found that a concentration of students in a neighborhood could be covered by a number of overlapping templates (Figure 3), a bus stop on any street section in

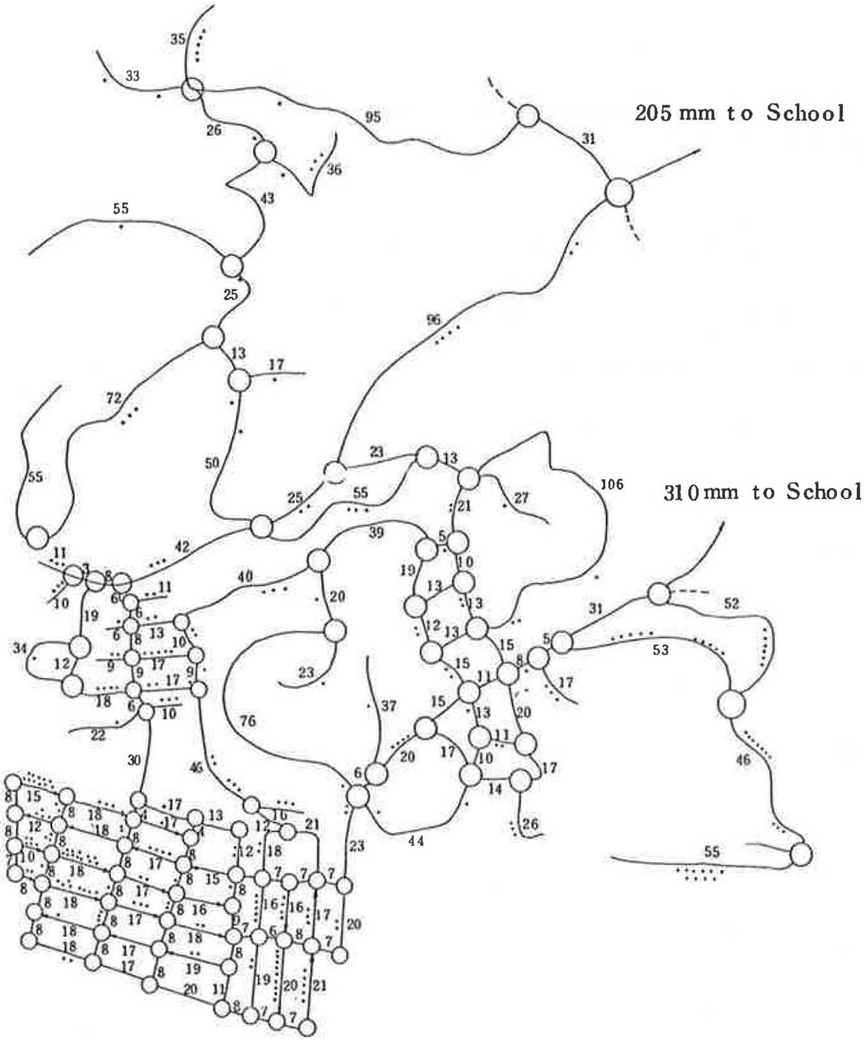

FIGURE 1 Sample subdistrict: dots represent homes of students. (Scale: 150 mm = 1 mi.)

the overlapping area would be within 50 mm (representing one-third mile) of all the covered students.

This is a trial-and-error method that is intellectually unpretentious. It does, however, systematize the incorporation of the first goal—the service attribute of maximum walk distance—into the process of siting bus stops, without the considerable effort and expense that would accompany use of the computer. Besides, retaining human judgment in this step may allow those "extra" bus stops to be placed in more desirable locations than a computer routine would, and where better bus routes can be achieved. Figure 4 shows 21 bus "zones" corresponding to the areas covered by the templates used in the sample subdistrict. Note that choosing different kinds of geometric shapes to cover student homes may result in a different number of total service zones and students in a zone. The current example does not exploit the possibility to overlap zones in the lower left area of Figure 3, but it could be done. Doing so in this neighborhood would create fewer bus stops, each with large number of students, which might not be desirable from the viewpoint of safety or public order.

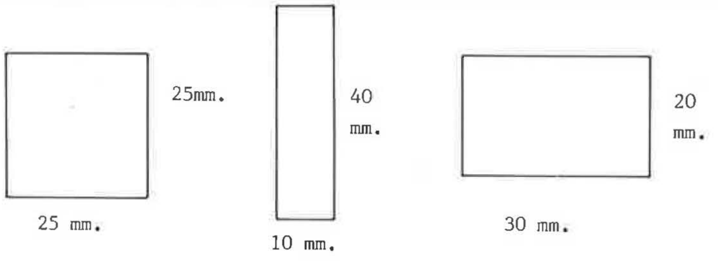

FIGURE 2 Examples of templates that ensure acceptable walking distance.

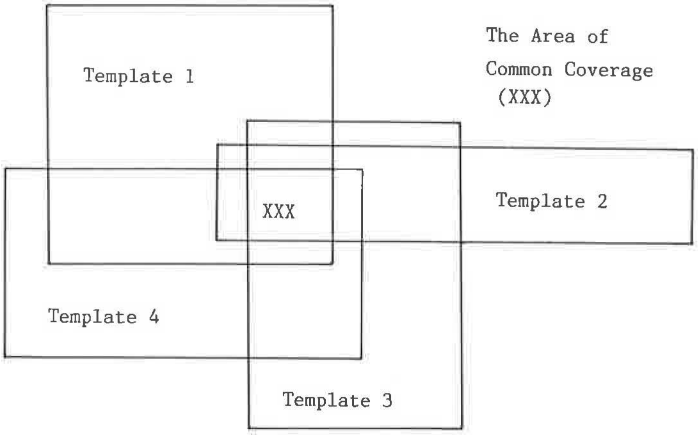

FIGURE 3 Exploiting overlapping templates to site bus stops.

Step 4—Develop Network Structure

To develop models for simulating the performance of the system, a suitable representation of the study area is first specified. By using the templates to establish bus stop zones in the previous step, not only have we avoided a potentially costly Facility Location Problem solution, but we have dispensed with the need for a detailed representation of the subdistrict's street network. Having systematically chosen a "good" bus stop location for each zone, only those street links

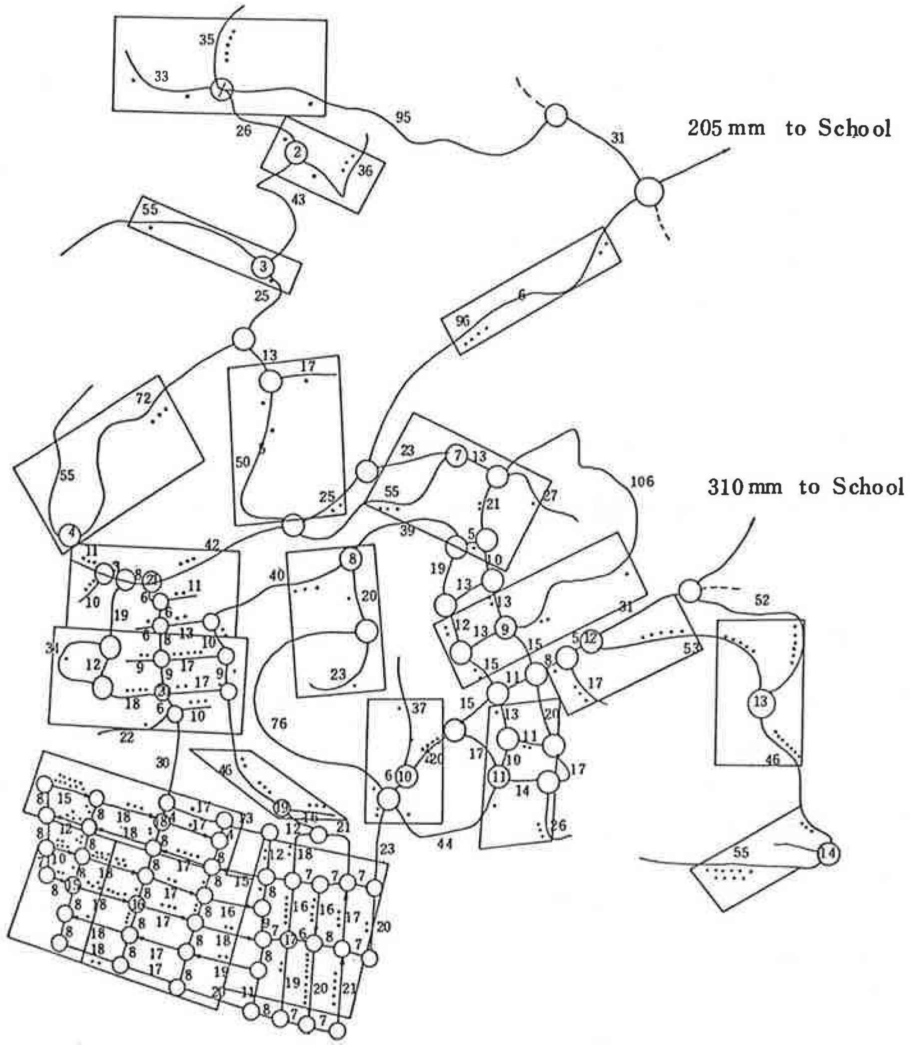

FIGURE 4 Subdistrict "covered" by 21 templates.

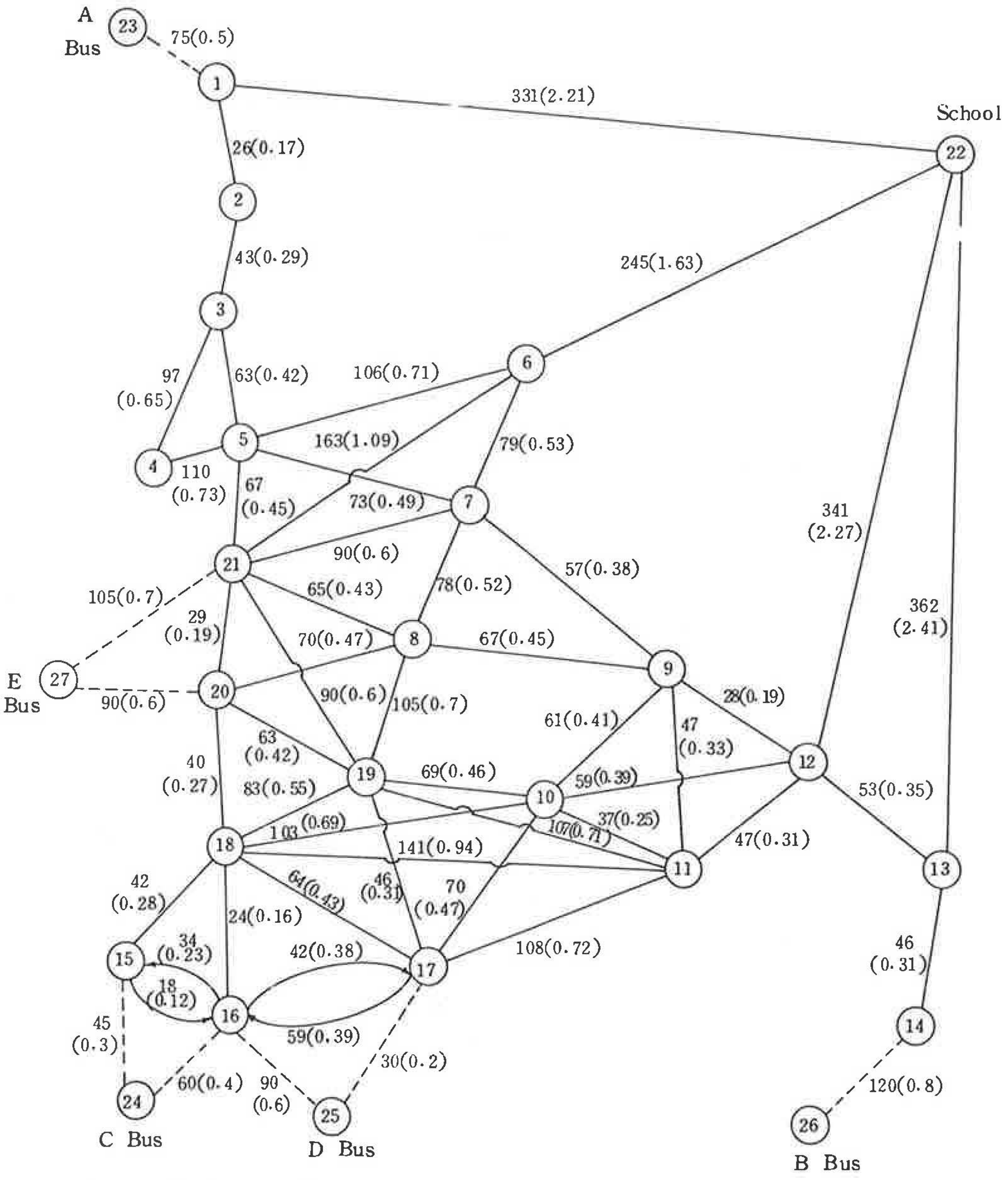

FIGURE 5 Link-node representation of the subdistrict with measure distance (actual distance).

that best connect the resulting set of bus stops need to be identified, measured, and encoded. The choice of bus stop locations can have much to do with the quality of the routes connecting them. This should be recognized as early as the application of the template step. A side street location may minimize the total walking distance for all students or the total longest distance any student that has to walk, but it will cause the school bus to leave a more direct, higher-speed route to reach it. In the example, bus stops are tentatively located at major intersections as zonal centroids. This simplifies the construction of link-node representation (Figure 5), by having bus stop at already existing nodes. Once the bus routes are determined, bus stops can be moved to more appropriate locations in each zone along the route. Twenty-one bus stops cover all 270 student homes in the study area. The distance along the principal routes connecting these nodes are shown in Figure 5. The number within parentheses is the actual road distance in miles.

Let us make five buses available to the service area: 2 of capacity 70, 2 of capacity 60, and one with 50 seats. Thus, we have a total seat capacity of 320 to transport the subdistrict's 270 students. The resulting average load factor of 87 percent can be used to establish values for the third goal. If avoiding underuse of any bus is considered, a minimum load factor less than 87 percent in this example, such as 70 percent, can be established. It is also necessary to know the location of bus starting points. The buses can all be located at one depot or at several different positions (such as drivers' homes), depending upon existing procedures. In this example, it is assumed that each bus has a different starting point. These locations are nodes 23 through 27 in Figure 5.

Step 5—Assign Students to Buses

In view of the multiple-objective nature of the school bus routing problem, one available solution technique is Goal Programming (GP). The basic concept of GP involves incorporating multiple, conflicting goals into one model. The GP model wants to optimize all specified goals, by trying to minimize the deviation (d^+ or d^-) of solution values from prespecified goals, while respecting the priorities given each goal and satisfying the problem's set of constraints. All goals are considered simultaneously or can be taken in turn, depending upon the characteristics of the problem and flexibility of the computer program.

A general review of Goal Programming was presented by Ignizio (*13*). Although misunderstanding and misuse of GP makes it controversial (*14*), it applies to the school bus routing problem because it can handle conflicting objectives in one formulation. Furthermore, computer packages are available, as are program listings in textbooks (*15*). Goals 1 through 5, as described earlier, are considered here in the context of the GP formulation.

1. Specify zones to be served by a bus:

$$\sum_{i \in T} X_{ij} + d_j^- = \sum_{i \in T} S_i \qquad j = 1, 2, \ldots, 5 \tag{1}$$

where

S_i = total number of students in zone i specified to be served by bus j.
d_j^- = number of students in specified zone i that are not served by bus j.

2. Guarantee each eligible student transportation to school:

$$\sum_{j=1}^{5} X_{ij} + d_i^- = S_i \qquad i = 1, 2, \ldots, 21 \tag{2}$$

where

X_{ij} = number of students at zone i to be assigned to bus j.
S_i = total number of students at zone i.
d_i^- = number of unserved students in zone i.

If d_i^- can be forced to zero, each student in zone i will have transportation to school. Note that each zone can be served by more than one bus. This allows service to zones with large student populations and permits better solutions with respect to overcrowding and unbalancing problems.

3. Avoid underuse of buses:

$$\sum_{i=1}^{21} X_{ij} + d_j^- = P \times C_j \qquad j = 1, 2, \ldots, 5 \tag{3}$$

where

P = minimum load factor of each bus, using a value of 0.7.
d_j^- = number of students lower than the specified minimum number of students in bus j.

This is intended to guarantee that at least the proportion P, $0 \le P \le 1$, of bus capacity is occupied if any bus is used. The value of P should, of course, be less than the average load factor—87% in this example.

4. Avoid circuitous routes:

$$\sum_{i \in U} X_{ij} - d_j^+ = 0 \qquad j = 1, 2, \ldots, 5 \tag{4}$$

where

d_j^+ = the number of students in zone i served by bus j, whose starting point is considered to be too far from i.
U = set of zones whose locations make service by bus j unsuitable.

This optional goal is sometimes added to save the solution process by ruling out obviously poor zones for a given bus to serve. For example, in Figure 5 bus A could not economically include zones such as 14 and 17 on its route, when several other buses start much closer to them.

5. Avoid overcrowding in each bus:

$$\sum_{i=1}^{21} X_{ij} - d_j^+ = C_j \qquad j = 1, 2, \ldots, 5 \tag{5}$$

where

C_j = capacity of bus j.
d_j^+ = number of students in excess of the capacity of bus j.

This goal discourages the assignment of students to a bus j beyond its carrying capacity. The capacity of each bus is shown below:

Bus	*Capacity*
A	50
B	60
C	70
D	70
E	60

An administrator can specify a set of $\{T\}$ zones that should be served by bus j for whatever reason. This is another optional goal that demonstrates the flexibility of GP. It should be emphasized that the GP solution will attempt to achieve this goal, unless doing so will prevent achievement of higher priority goals or cause violation of some constraints.

Equations 1 and 4 are used here to incorporate transportation costs into the GP formulation. In a GP formulation, costs cannot be represented in a direct way. Attempts at doing so are often necessarily crude (*16*). This is because the GP decision variables represent assignment of students (in zones) to buses. The sequence of zones that forms the shortest bus route cannot be found in a standard GP formulation. On the other hand, routing algorithms place almost total emphasis on minimizing system costs. The conflicts often arise when different goals are considered. The GP objective function involves minimizing the deviations, either positive or negative, from predetermined goals. Priorities indicate the relative rank assigned by the user appear as coefficients P_i. Such a case arises when one or more of the goals clearly is far more important than the others. This type of problem belongs to the category of preemptive goal programming (*17*). Obviously, different priorities order will result in different solutions. The GP model will determine the number of students in each zone to be assigned to each bus by considering five multiple goals simultaneously. The objective function (Z) for our example is given as follows:

$$\text{Minimize } Z = P_1 \sum_{i=1}^{21} d_i^- + P_2 \sum_{i \in T} d_i^- + P_3 \sum_{i \in U} d_i^+ + P_4 \sum_{i=1}^{5} d_i^+ + P_5 \sum_{i=1}^{5} d_i^-$$

where P_1 is the coefficient of the goal having the highest priority.

A complete formulation of the generalized GP model for this example is presented here.

$$\text{Minimize } Z = P_1 \sum_{k=1}^{21} d_k^- + P_2 \sum_{k=76}^{80} d_k^- + P_3 \sum_{k=32}^{75} d_k^+ + P_4 \sum_{k=22}^{26} d_k^+ + P_5 \sum_{k=27}^{31} d_k^-$$

Subject to

$$\sum_{j=1}^{5} X_{ij} + d_k^- = S_i \quad (\text{for } i = 1, \ldots, 21; k = 1, \ldots, 21)$$

$$\sum_{i=1}^{21} X_{ij} - d_k = C_j \quad (\text{for } i = 1, \ldots, 5; k = 22, \ldots, 26)$$

$$\sum_{i=1}^{21} X_{ij} + d_k = P \times C_j \quad (\text{for } j = 1, \ldots, 5; k = 27, \ldots, 31)$$

$$\sum_{i \in U} X_{ij} - d_k^+ = 0 \quad (\text{for } j = 1, \ldots, 5; k = 32, \ldots, 75)$$

$$\sum_{i \in T} X_{ij} + d_k^- = \sum_{i \in T} S_i \quad (\text{for } j = 1, \ldots, 5; k = 76, \ldots, 80) \; X_{ij}, d_k^-, d_k^+ > 0$$

Step 6—Analyze the Output and Form the Bus Routes

The example problem had 80 goal constraints with 105 variables and 5 major objectives. The problem was solved using a modified FORTRAN GP computer program (*15,18*) on a VAX 11/780 system at Purdue University. The program required 504 seconds of execution time for the formulation described in Equations 1 through 5. The output is shown in Table 1.

Since the major variables X_{ij} used in this GP represent the number of students at zone i to be assigned to bus j, the output will show the result of aggregating several zones to a specific bus. Once the assignment of students and zones to each bus has been determined by this GP model, the estimated transportation cost can be easily obtained from any appropriate routing algorithm or even manually. For example, $X_{102} = 9$ in Table 1 means that 9 students from zone 10 would be assigned to bus B (bus number 2). It also can be seen from the first column that 48 students from 8 zones would be transported by bus A. Since the capacity of bus A was 0, its load factor is 96 percent, somewhat higher than the 87 percent system average. Bus D, serving 52 students in zones 17 and 18, has a 74 percent load factor. Note that zone 18 is served by buses C and D, demonstrating that each bus zone can have more than one bus serving it.

Once the aforementioned assignments have been determined, the next step is to form efficient bus routes. What is desired here is a method that is easy to obtain or program yourself, cheap to run, or dispenses with computer routines entirely (*19*). One can use the shortest distance matrix (from Figure 5) or traveling salesman algorithm (*2, 20*) to establish bus routes through the assigned stops. This is a straightforward step. Since the GP assignment (Table 1) has relieved routing algorithms of the need to decide which bus serves a given node, they need not be very elaborate. In fact, applying a computer route to find bus D's route (through only two

TABLE 1 ASSIGNMENT OF EACH BUS FROM THE OUTPUT OF GP

	A Bus	B Bus	C Bus	D bus	E Bus
	$X_{11} = 8$	$X_{62} = 3$	$X_{193} = 8$	$X_{174} = 35$	$X_{65} = 3$
	$X_{21} = 5$	$X_{82} = 5$	$X_{183} = 12$	$X_{184} = 17$	$X_{215} = 17$
	$X_{31} = 2$	$X_{142} = 13$	$X_{153} = 24$		$X_{205} = 22$
	$X_{51} = 5$	$X_{132} = 17$	$X_{163} = 26$		
	$X_{51} = 5$	$X_{112} = 11$			
	$X_{71} = 5$	$X_{102} = 9$			
	$X_{91} = 9$				
	$X_{121} = 9$				
Total	48	58	70	52	42
Capacity	50	60	70	70	60
Load Factor	96%	96.6%	100%	74%	74%

TABLE 2 ROUTE SOLUTIONS FOR EACH BUS

Bus	Route	Distance (miles)
A	23 -1 -2 -3 -4 -5 -7 -9 -12 -22	5.67
B	26 -14 -13 -11 -10 -8 -6 -22	5.56
C	24 -15 -16 -18 -19 -22	4.25
D	25 -17 -18 -22	3.81
E	27 -20 -21 -6 -22	3.51
Total		22.80

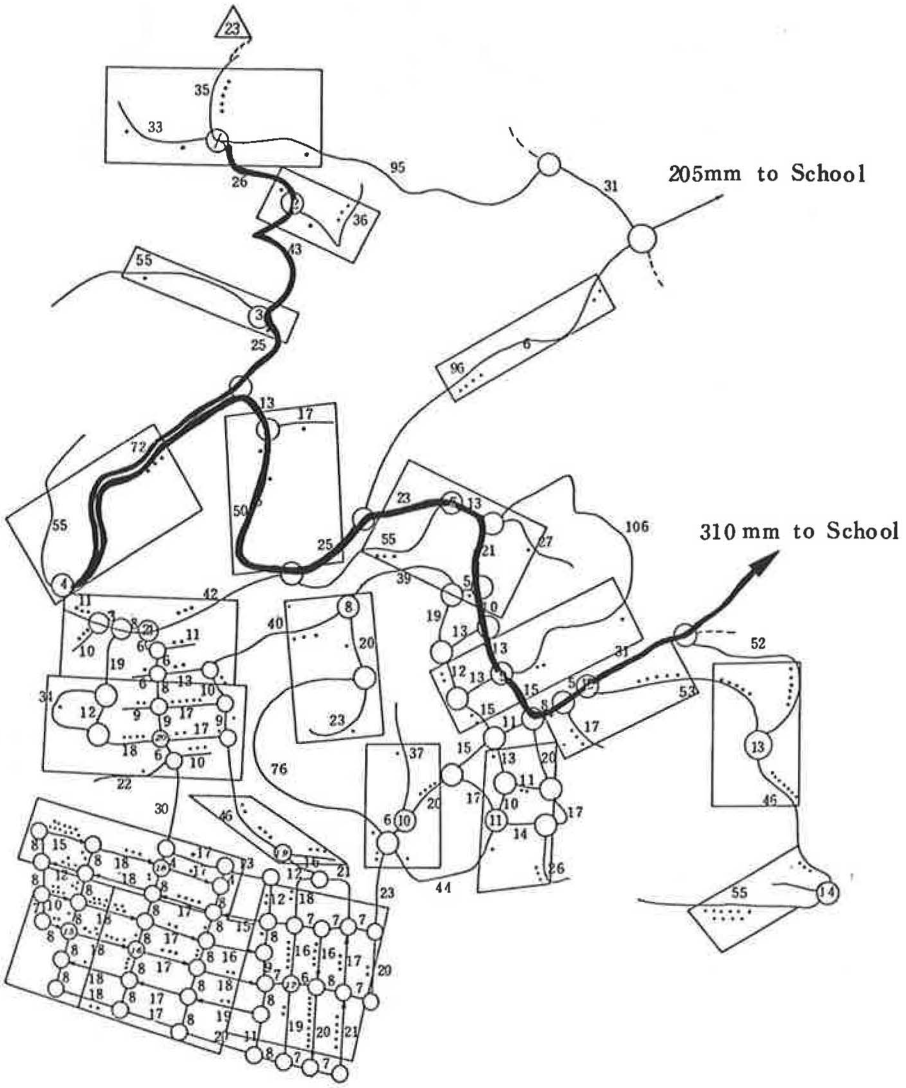

FIGURE 6 Bus A's solution route.

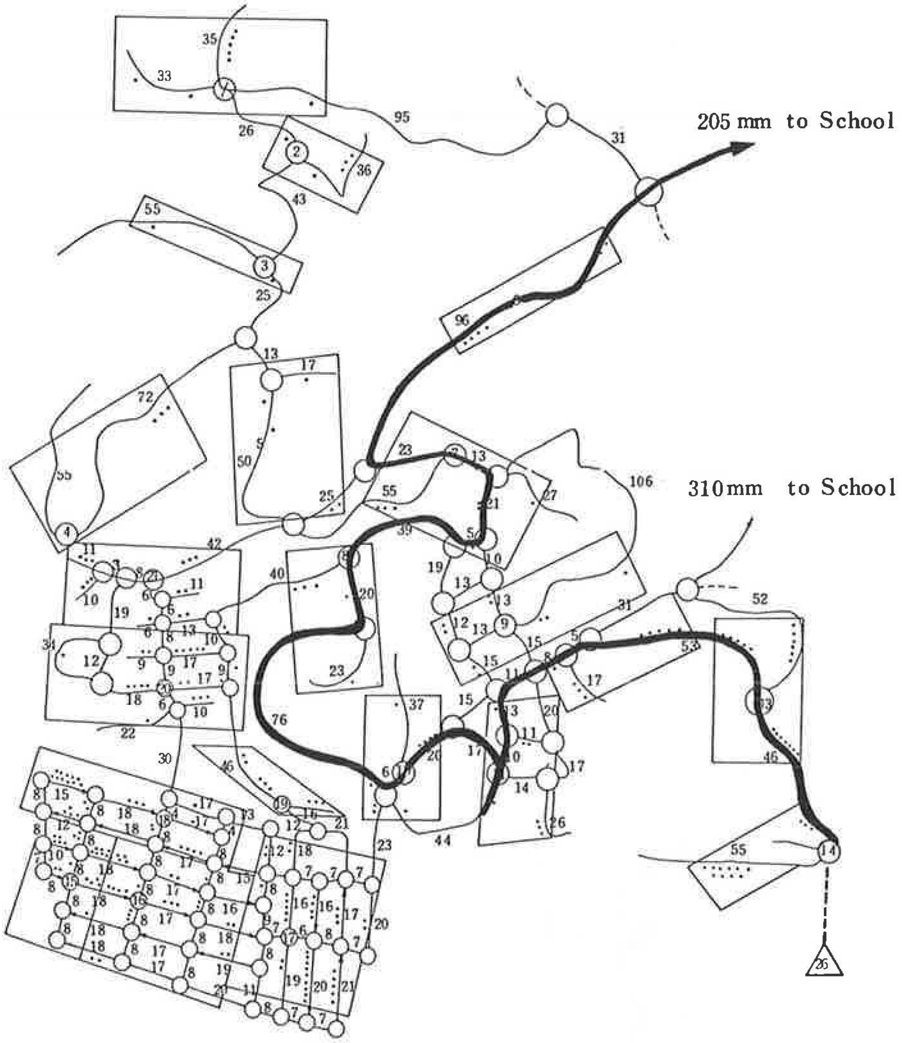

FIGURE 7 Bus B's solution route.

stops) would be absolutely wasteful. Sometimes, the GP assignment solution reduces the routing problem to such an extent that its solution is trivial, as bus D's route case. Table 2 records the length of each bus route shown in Figures 6 to 10.

COMPARISON OF SCHOOL BUS ROUTING ALGORITHMS

Although a number of articles describe school bus routing algorithms, most published works are concerned with the construction of bus routes from a set of given depots or bus stops to a single school. They can be grouped into two distinct approaches. The first is called the "cluster first—route second" procedure for routing. It forms a cluster of bus stops that are feasible with respect to the travel time and bus capacity constraints, and then finds the best route for the stops in each cluster by reducing as much as possible the travel time to cover all bus stops within each cluster (*9*). This "cluster first" algorithm has been proposed by many researchers, such as Bennett and Gazis (*21*), Gillett and Miller (*22*), Krolak and Williams (*1*), and Chapleaun et al. (*23*). The other approach, called "Route first—cluster second," first creates a single route through all stops, using a heuristic traveling salesman algorithm, and then divides this single route into feasible shorter routes by considering the bus capacity and travel time constraints. Many interesting aspects of this problem has been discussed by Newton and Thomas (*24*), Mandl (*25*), and Bodin and Berman (*9*).

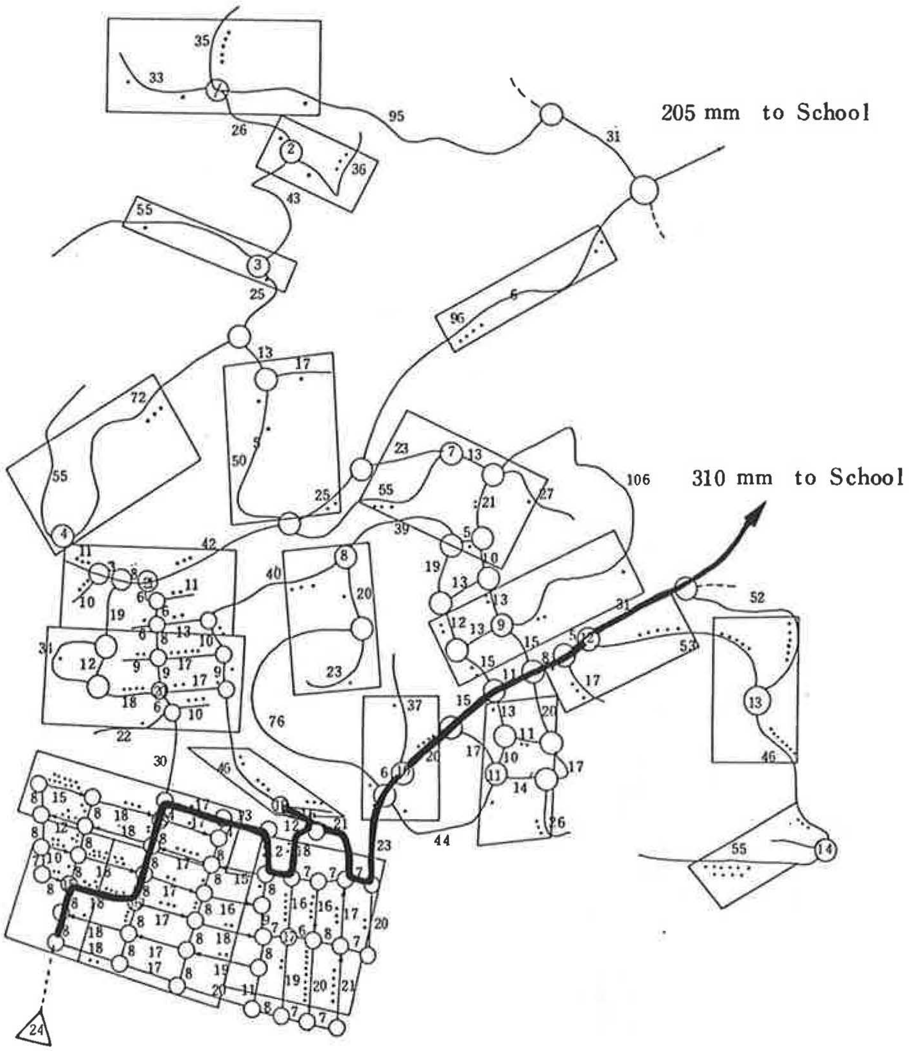

FIGURE 8 Bus C's solution route.

A brief comparison of some approaches with our proposed algorithm, including techniques and computing time, is summarized in Table 3. In the authors' experience, a general result in comparing heuristic algorithms in terms of efficiency is very seldom obtainable, because most heuristic algorithms handle the problems with different objectives, constraints, or characteristics which often require special treatment. For example, the location and demand of bus stops were assumed to be known in most traditional school bus routing algorithms. If these two elements are made part of the problem to be solved, then the formulation and methodology would be quite different. Naturally, the adoption of suitable algorithms depends upon the requirements and criteria set by administrators or by the computer packages available.

In this paper, a new practical algorithm is proposed to consider the school bus routing problem in either urban or rural areas. The use of templates and GP strategy is much more flexible and easier to adapt to many conflicting objectives specified by school administrators. It should be noted that the current GP formulation does not consider the scheduling problem. With scheduling (time windows), the complete set of routes cannot be specified beforehand, since the exact time of service for a given route cannot be ascertained in advance. Hence, it becomes difficult to construct the complete network of possible connections a priori. More effort is necessary to include scheduling of buses in order to reflect the real world. An extensive discussion of routing and scheduling was given by Bodin et al. (*26*), Bodin and Berman (*9*), Desrosiers et al. (*27*), and Swersey and Ballard (*25*). Development of combined school bus stop location, routing, and scheduling

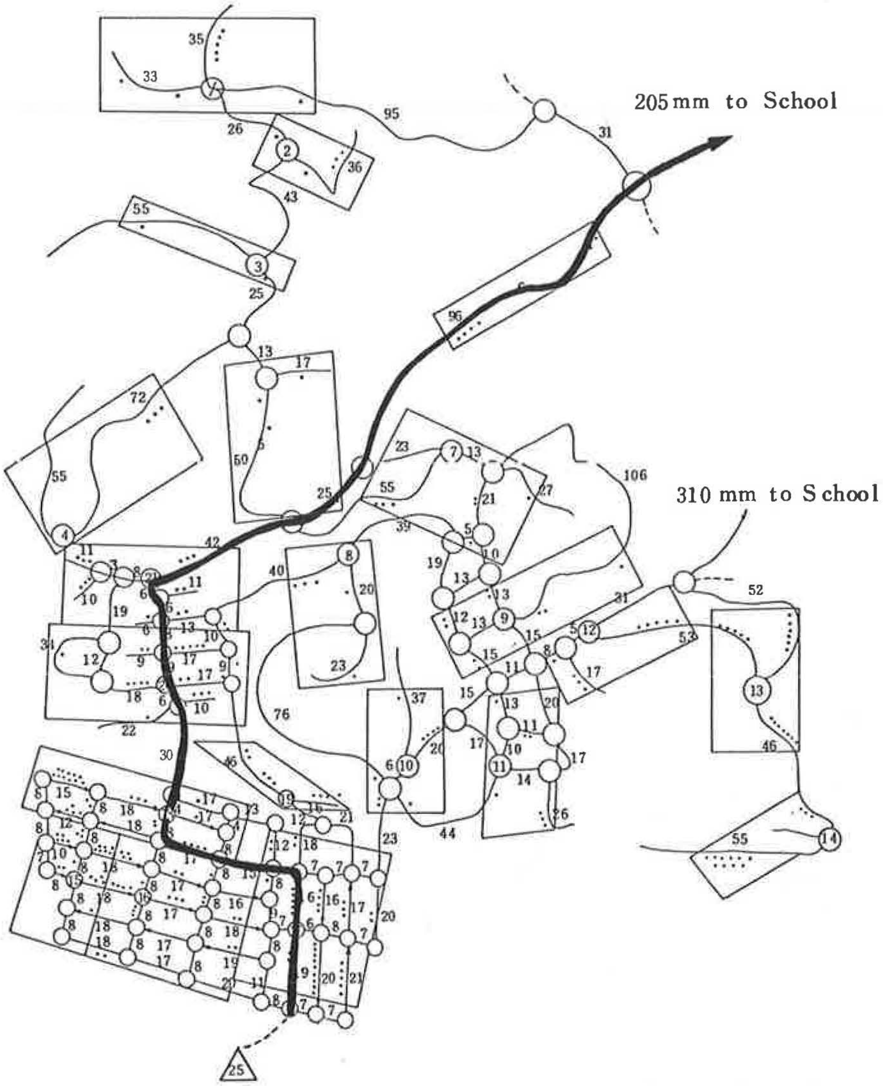

FIGURE 9 Bus D's solution route.

models is a fertile area for future research. Some exact and heuristics with respect to the formulation and solution of combined models have been studied by Tsay (*2, 6*), Perl and Daskin (*29*), and Srikar and Srivastava (*4*).

The limitation of the proposed algorithm is mainly on the capabilities of available GP packages. Its computer time will increase rapidly as the number of bus stops are added. In order to achieve savings in total cost, the entire school residential area must be broken down into manageable parts. In addition, this algorithm should involve human judgment for the use of templates and computer analysis of GP; school administrators may experience difficulty in performing sensitivity analysis on various priorities order and template sizes.

CONCLUSIONS

A practical solution to a network problem has been proposed. An important element of service—a limit on student walking distance—can be incorporated into the siting of bus stops at practically no cost by using templates. Goal Programming is used to balance conflicts between multiple predetermined goals. Finally, the best route of each bus is obtained through the application of any routing algorithm to a greatly reduced problem. Thus, school bus routing can be accomplished without an exotic operation by computer. In fact, retaining human involvement in establishing goals and giving them desired weight in a multi-objective solution process, should lead to an infinitely more satisfactory result.

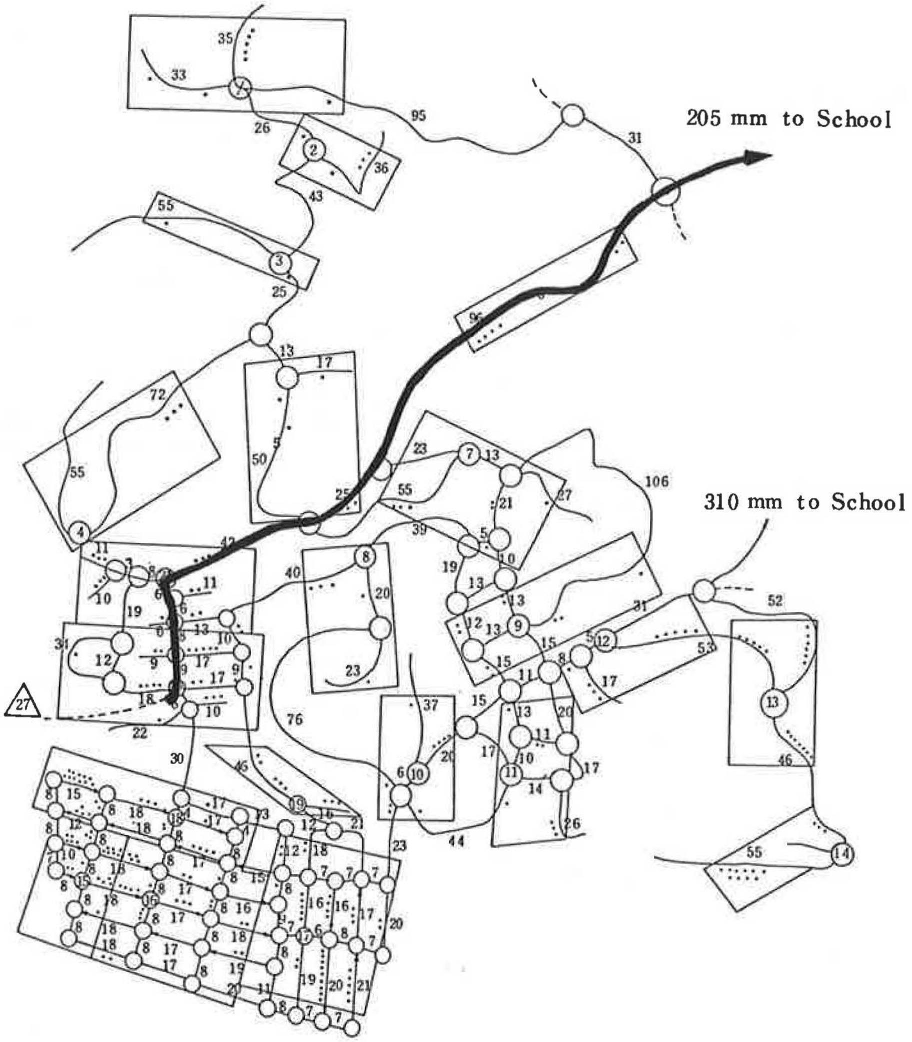

FIGURE 10 Bus E's solution route.

TABLE 3 COMPARISON OF SCHOOL BUS ROUTING ALGORITHMS

Study	Type	Location of Bus Stops	# Students at Each Stop	Method to Build School Bus Routes	Computing System; Example and Computer Time
Tsay and Fricker (1987)	Cluster first -route second	Use templates that guarantee students' maximum walking distance	Unknown	1. Use GP to solve multiple objectives 2. Assign students to each bus 3. Apply shortest path or traveling salesman algorithm to obtain routes	VAX 11/780; 270 students, 5 buses, 21 stops; 504 seconds.
Bennett and Gazis (1972)	Cluster first -route second	Given	Given	1. Extension of Clarke and Wright algorithm to start with many short routes 2. Decrease the number of routes by combining two tours into a single tour	256 bus stops, No execution times given.
Newton and Thomas (1974)	Route first -cluster second	Given	Given	1. Use traveling salesman route to encompass all bus stops 2. The route is partitioned into segments that satisfy bus capacity and maximum route length constraints	CDC 6400; 532 students, 45 stops; 36.5 sec. 596 students, 37 stops; 6.9 sec. 1097 students, 76 stops; 136.9 sec. 6 schools, 669 students, 96 stops; 61 seconds.
Bodin and Berman (1979)	Route first -cluster second	Mini-Stops plus scheduling	Unknown	1. Apply Lin's 3-opt branch exchange set of routes that satisfy the bus capacity and student travel time constraints	NCR Century 200 34 buses: 12 hours. 13 buses: 11 hours. 28 buses: 6 hours.

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NJ TRANSIT Process for Evaluating Capital Projects

DONNA D'ORO

In June 1987 NJ TRANSIT proposed a $1.3 billion plan for rail and bus improvements that would handle projected growth in trans-Hudson commuting traffic. To evaluate projects, NJ TRANSIT used standard financial cost/benefit analysis techniques and considered the major impact of transportation investments on New Jersey's growing economy. Among the concerns commonly faced by a public agency is the weighing of the public policy benefits of an investment along with its cost-effectiveness and efficiency.

NJ TRANSIT was faced with the task of selecting, among many capital investment initiatives, the set of projects that would best meet transit travel needs in New Jersey. The main problems to be addressed by the agency were the growth in trans-Hudson travel and the capacity limits of the current transportation system. The ability to increase rail capacity to Penn Station New York (PSNY) and bus capacity through the Lincoln Tunnel to the Port Authority Bus Terminal (PABT) formed the cornerstone of the planning effort. Capacity for each transit mode was upgraded—increasing the number of peak hour buses to the PABT by approximately 200, relieving currently overcrowded approaches to the Lincoln Tunnel, and increasing the number of peak hour trains into PSNY from 20 to 30. These upgrades would make it possible to handle projected trans-Hudson growth, as well as opening the door for consideration of several rail project options (*1*).

The list of rail projects was comprehensive, addressing each of the Trans-Hudson transportation corridors and in some cases including alternative ways of handling the same transit market. NJ TRANSIT organized these options according to geography, as New Jersey's growth patterns differ by area, and the range of potential transit improvements in each travel corridor varies (see Figures 1 and 2). The methods used to evaluate these rail projects played a key role in the organization's decision-making.

From the beginning, NJ TRANSIT realized that its evaluation must include quantitative assessments of transportation effectiveness and efficiency. Qualitative measures would assess the impact of a project on state development, policy concerns, and external issues such as the environment, coordination with other regional transportation agencies, and risk factors. These concerns, common to public sector decision-making, involve balancing the public policy benefits of an investment with measures of cost-effectiveness and efficiency. In the private sector the basis for decision is much more clearly defined—maximum profit must be made. In the public sector, however, social, political, and environmental priorities may prevail (*2*).

In developing an annual capital program, NJ TRANSIT understood the importance of including qualitative judgments as to a project's net worth in the decision-making. Proposed projects are analyzed as to both their financial and nonmonetary costs and benefits (*3*). However, the annual capital program, which encompasses mostly routine capital replacement and major rehabilitation, does not include regional initiatives aimed at capturing new markets. NJ TRANSIT found it necessary to expand the evaluation criteria used in its annual capital process to make regional investment decisions. Key policy concerns were the effect of a project on local economic development, private bus operators, auto congestion, and intrastate mobility. In addition, NJ TRANSIT analyzed a set of alternatives for not just a single transportation corridor, but for an entire network of geographic corridors combined into one conceptual corridor of trans-Hudson travel. The variety of individual projects competing for selection demanded full examination of the regional impacts of each project, rather than merely its financial costs and benefits (*4*).

It was important that the evaluation provide a method to judge each project fairly and consistently compared to other projects under consideration. The objective of the evaluation was to select projects that, taken together, could solve the needs of trans-Hudson travelers and make the most use of possible new transportation capacity into New York.

PROJECT OPTIONS

NJ TRANSIT grouped the project options into four geographic travel corridors: Bergen County, Morris and Essex Counties, Newark District, and Monmouth and Ocean Counties. A brief description of the project options follows.

Bergen County

West Shore Connection to New York Penn Station, West Shore Transfer, West Shore to Hoboken

The West Shore options involve restoring passenger rail service on the West Shore rail line in Bergen County, New Jersey, and Rockland County, New York. The West Shore corridor currently has the largest share of trans-Hudson auto commuting of the trans-Hudson corridors. The connection option would provide direct one-seat rail service to New York Penn Station by constructing new connecting track at Secaucus between the West Shore Line and the Northeast Corridor, while the transfer option would involve a passenger transfer

New Jersey Transit Corporation, Inc., Department of Planning, McCarter Highway and Market Street, Newark, New Jersey 07101.

BERGEN COUNTY
West Shore Connection to Penn Station New York
West Shore Transfer
West Shore to Hoboken
Secaucus Connection
Secaucus Transfer
Secaucus Transfer and West Shore Transfer

MORRIS AND ESSEX COUNTIES
Bay Street Connection
Kearny Connection
Manhattan Transfer
Kearny Connection and Bay Street Connection

GROWTH IN NEWARK DISTRICT
Raritan Valley Dual Mode
Northeast Corridor Expansion
North Jersey Coast Line Expansion
North Jersey Coast Line Dual Mode

MONMOUTH AND OCEAN COUNTIES
Old Bridge Extension
South Amboy to Lakewood
Red Bank to Lakewood

FIGURE 1 Project options.

station at Secaucus. The transfer station would allow passengers to travel to New York Penn Station with one transfer as well as to connect to other lines that use the Northeast Corridor. The West Shore to Hoboken option involves connecting the West Shore line to the Bergen County line, which terminates in Hoboken. A bus shuttle would operate from Hoboken to midtown Manhattan, or passengers could transfer to PATH trains or the planned Hoboken ferry for final connections to lower Manhattan.

Secaucus Connection/Transfer

The Secaucus connection and transfer projects also attempt to deal with the high auto use in the Bergen County area by providing rail service to midtown Manhattan that does not currently exist. The connection option would involve direct connecting track from the Main, Bergen, and Pascack Valley lines to the Northeast Corridor. The transfer option would involve a passenger transfer station at Secaucus.

Morris and Essex Counties

Bay Street Connection

The Bay Street connection would consolidate two relatively weak rail lines, the Boonton Line and the Montclair Branch, reducing costs for operation and capital maintenance.

Kearny Connection and Manhattan Transfer

The Kearny connection would provide direct rail access to midtown Manhattan through construction of a track connection between the Morris and Essex lines and the Northeast Corridor. It would also link the Newark Broad Street station directly with New York Penn Station, further supporting growth and redevelopment in downtown Newark. The Manhattan transfer is a transfer alternative to the Kearny connection.

Newark District

Raritan Valley Dual Mode and North Jersey Coast Line Dual Mode

These two projects call for dual power diesel-electric locomotives that would provide a one-seat, no-transfer ride to New York Penn Station for the passengers currently riding these lines.

Northeast Corridor and North Jersey Coast Line Expansion

These projects involve trains, new stations, additional parking, and train yard expansions to accommodate rail ridership growth on the Northeast Corridor and North Jersey Coast Line.

Monmouth and Ocean Counties

The Old Bridge Extension, South Amboy to Lakewood, and Red Bank to Lakewood projects would bring new rail service to the rapidly growing market in central New Jersey. The options involve branch lines off the North Jersey Coast Line that take advantage of existing rail right-of-ways.

EVALUATION CRITERIA

A list of evaluation criteria was prepared with the help of representatives from departments in corporate headquarters and the Bus and Rail subsidiaries through NJ TRANSIT's Strategic Planning and Policy Committee. The criteria were chosen to address the concerns of three major constituencies defined as the operator (NJ TRANSIT); users (passengers); and non-users (auto users, government, other operating agencies, community organizations, etc.) By focusing on these three different constituencies, NJ TRANSIT achieved a broad perspective in selecting its criteria. NJ TRANSIT concerns emphasized the need for cost-effective, financially feasible, low-risk solutions; passenger concerns emphasized the importance of travel benefits; and non-user concerns directed attention to issues such as relief of traffic congestion, economic development, and providing transit services to new markets.

The proposed list of criteria was examined next in light of the data available for each project. NJ TRANSIT possessed a mode-split ridership model that provided much of the data required to calculate travel benefits and ridership changes for

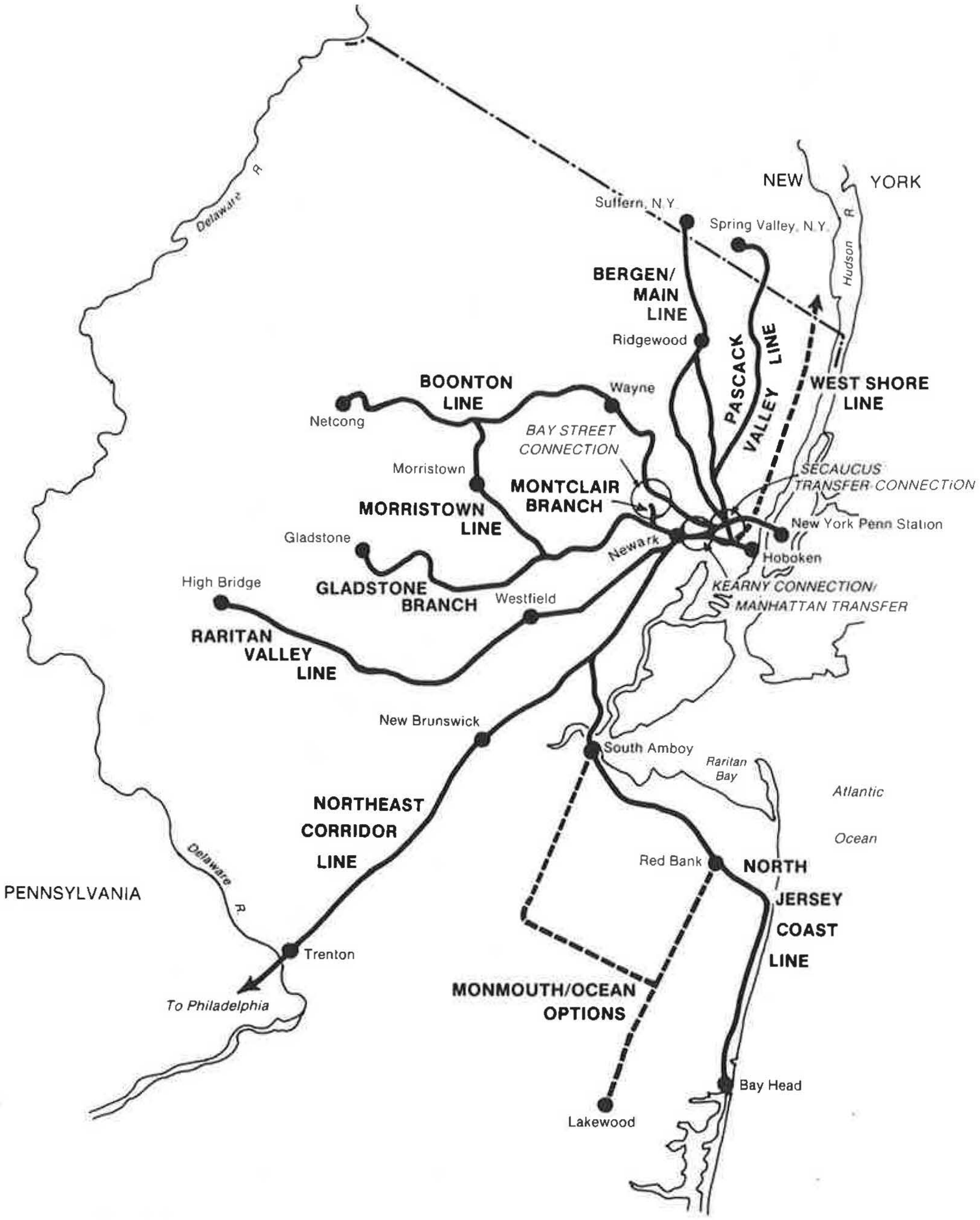

FIGURE 2 NJ TRANSIT rail system—proposed rail projects.

each project alternative. The model also provided revenue estimates of projects based on ridership projections. Preliminary estimates of capital costs for each project were based on engineering studies, and operating costs were based on the ridership and service plan for the project. Thus, most of the data required to calculate the criteria were available. Two areas that could not easily be addressed with hard quantitative data were environmental impacts and economic development. Consequently, these areas were included in the evaluation process as qualitative rather than quantitative indicators. A list of the quantitative criteria used, together with their definitions, is included as Table 1. The criteria were grouped into the following three categories:

Financial Analysis

The costs and benefits of a project as an economic investment and its effect on the operating efficiency of the system. The criteria are rate of return, net present value, farebox recovery, deficit per new passenger.

User Benefits

The travelers who would benefit from an investment and quantification of their benefits as travel time savings, transfer savings, and rider trip costs. Criteria are total transit riders,

TABLE 1 EVALUATION CRITERIA DEFINITIONS

CRITERIA	DEFINITION
A. FINANCIAL ANALYSIS	
(1) Return on Investment	The present value of the net operating costs (operating costs minus revenue) divided by the present value of capital costs.
(2) Net Present Value	The present value of the net operating costs minus the present value of capital costs.
(3) Farebox Recovery	Passenger revenue divided by the direct cost of providing service at the mode level.
(4) Deficit/New Passenger	The net cost of providing service before the investment minus the net cost of providing service after the investment divided by the additional number of passengers carried.
B. USER BENEFITS	
(1) Total Riders	The number of transit passengers who would be affected by an investment in a given corridor.
(2) % Change in Riders	The transit ridership for the corridor gained as a result of the capital investment divided by the ridership in the corridor without the capital investment.
(3) Peak Riders Benefitted	The number of transit passengers who would use the new transit option in the corridor.
(4) New Riders By 1995	The number of new riders attracted to the transit mode as a result of the capital investment. New riders do not include existing direct rail riders.
(5) Change in Total Travel Time	The change in total travel time for the corridor.
(6) Change in Trip Cost	The percentage change in total trip cost for the corridor compared to the total trip cost in the corridor without the capital investment.
(7) Directness	The percentage change in number and type of transfers for all passengers in the corridor compared to the number and type of transfers in the corridor without the capital investment. Rail/PATH transfers are given a different weight than Rail/Rail, Auto/PATH, and Auto/Bus transfers.
C. REGIONAL IMPACTS	
(1) Peak Period Diverted Auto Trips	The total number of trans-Hudson auto trips diverted during the peak period.
(2) New Jersey Growth	The number of new trips generated by making the capital investment divided by the number of total additional trans-Hudson New Jersey trips expected by forecasted growth in New Jersey population and labor force.
(3) Transit Market Share	The increase in the percentage of peak period trans-Hudson transit trips in the corridor.
(4) Private Bus Impact	Ridership impact on private bus.

change in riders, peak riders benefited, new riders, change in travel time, change in transfers, change in trip cost.

Regional Impacts

The relationship of the project to the regional transportation network. Criteria are peak period diverted autos, private bus diversions, transit market share, New Jersey growth.

Besides these criteria, a series of non-quantifiable factors were developed. One set of factors, under the heading "risk," dealt with the complexity and uncertainty of project construction and operation. Eight factors were listed and each project was scored according to the number of risk factors involved and the degree of risk it presented. These judgments were made by the NJ TRANSIT planning and engineering staffs with help from consultants working on the various projects.

Matters of concern to NJ TRANSIT at the policy level were grouped under the heading "qualitative factors" and dealt with the way in which the proposed project would influence development, increase intrastate mobility, affect other transit providers, and elicit funding contributions. Nine factors were listed and, as with the risk factors, each project was scored on its ability to address these factors. The risk and qualitative factors are as follows:

1. Risk factors

- depends on dual-mode technology (locomotives that can operate with either diesel or electric power)
- requires rail yard expansion
- requires relocation
- adversely impacts private carriers
- involves other agencies (Amtrak, Conrail, etc.)
- difficult to provide parking
- long time to complete
- potential environmental barriers
- construction complexity, and
- operational complexity.

2. Qualitative factors

- supports urban development
- supports Meadowlands growth
- supports Waterfront development and Waterfront transitway
- creates transit opportunities to the Sports Complex and new baseball stadium
- interconnects New Jersey rail lines
- addresses problems in high auto-oriented areas
- minimizes impact on private bus operators
- attracts private funding participation, and
- attracts New York State contribution.

The evaluation criteria shown in Figure 3 would allow the different strengths and weaknesses of the projects to be presented in a comprehensive and consistent manner.

Financial Analysis Factors

- Return on Investment
- Net Present Value
- Farebox Recovery
- Deficit/New Passenger

User Benefit Factors

- Total Transit Riders in Corridor
- % Change in Total Transit Riders
- Riders Benefited by Project
- New Riders Attracted to Project
- Change in Travel Time
- Change in Quantity and Quality of Transfers
- Change in Trip Cost

Regional Impact Factors

- Peak Period Diverted Autos
- Private Bus Diversions
- Transit Market Share
- New Jersey Growth

Risk Factors

- Dual Mode Dependent
- Difficult to Provide Parking
- Requires Yard Expansion
- Requires Relocations
- Adverse Private Carrier Impacts
- Other Agency Involvement (Amtrak, Conrail, etc.)
- Time to Complete
- Environmental Issues
- Construction Complexity
- Operational Complexity

Qualitative Factors

- Private Bus Impact
- Inter-connects New Jersey
- Addresses Northern Suburbs
- Urban Development
- Meadowlands Potential
- Serves Waterfront
- Private/Public Participation
- Baseball Stadium
- New York Contribution

FIGURE 3 Evaluation criteria.

DATA COLLECTION AND ANALYSIS

To calculate the set of criteria indicators, each project was compared to a Transportation System Management (TSM) alternative in the same transportation corridor. A TSM option represents the best that can be achieved for mobility within the existing transportation infrastructure. Data on project costs and benefits were measured as an increment from the baseline condition defined by the TSM alternative. A consistent process was used to estimate the capital and operating costs for each project, based on its peak period ridership. The capital costs for many of the projects were preliminary, as engineering and design work was not complete. Operating costs (also preliminary) were used to compare projects and satisfactorily indicated the relative costs of the projects.

Each project was modeled and again compared to a TSM alternative to develop data on changes to ridership, revenue, travel time, transfers, and user costs. These data were collected in spreadsheets used to calculate the 15 quantitative criteria. Risk assessments as well as qualitative assessments were also developed for each project alternative.

In two cases criteria values were calculated for two projects together—the Secaucus transfer with West Shore transfer and the Kearny connection with Bay Street connection. In both cases, it was technically feasible to implement the two projects together. Market overlap existed between the Secaucus Transfer and West Shore projects to the extent that the market size of both projects together would be less than the sum of the two projects individually. Also, capital and operating costs overlapped to a considerable degree. In the case of Kearny/Bay Street, the two projects had a synergistic effect on each other so that a stronger market draw resulted when the projects were considered together.

A database was created for the 17 rail options (15 individual projects and two combination projects) listed in Figure 1, composed of 15 quantitative criteria, a risk rating, and a qualitative rating. The next task was to combine this information in a way that allowed NJ TRANSIT to judge which projects provided the best benefits to New Jersey for the capital dollars spent.

METHODOLOGY FOR DEVELOPING PROJECT RANKINGS

As the evaluation criteria span a wide range of factors, it was probable that a project would not perform equally well in each criteria group. A project having the potential to attract many new riders and save travel time might also be very risky. NJ TRANSIT wanted a way to combine the various elements considered in the evaluation criteria systematically. The goal to develop an objective basis for ranking the projects, considering all the evaluation criteria.

To do this a two-step process was followed. First, for each category—financial analysis, user benefits, regional impacts, risk, qualitative factors—a score was calculated for the overall performance of a project within that category. For example, in the financial analysis category, where the four evaluation criteria are rate of return, net present value, farebox recovery, and deficit per new passenger, a project's performance for each criterion was converted to a statistically standard normal value. (The normalized value was calculated as the difference between the actual value of the indicator and the mean value of the indicator for the projects divided by the standard deviation of the indicator for the projects.) The criteria could then be represented in equivalent units and added to create a composite score for performance in the financial analysis category. For each of the five categories, projects were ranked from highest performance to lowest performance, based on the values of the composite category indicator.

By grouping the criteria into categories and developing standardized values for each category, the large list of criteria was reduced to five representative scores. These scores provided a way to compare performance among the different categories, even though there was a different number of criteria in each category and overlap of criteria within a category. For example, the user benefits category had seven criteria compared to four in the financial analysis category, and four of those seven criteria dealt specifically with ridership changes.

The second step in the evaluation process involved standardizing the five composite values derived for each category and combining them to get an overall rating of each project's performance considering *all* categories. In this process, six different weighting methods were followed—first, all categories were given equal weights, and for the other five, each category in turn was weighted by two while the other four categories were weighted by one (see Table 2). In this way, it was possible to consider any one of the categories as more important than the others and see the effect that had on the rank order of the projects.

The evaluation process tended to show better performance overall for projects that addressed a larger commuter shed. This phenomenon did not exist in the financial analysis category, which compared revenues from ridership to costs incurred, but did occur in the user benefits and regional impacts categories. Both these categories dealt with the ridership that a project was able to attract. If a project attracted a large number of riders, it performed well. (The risk and qualitative factors categories did not deal specifically with ridership and, therefore, did not reflect this tendency.) Because of the emphasis on ridership, combinations of projects performed better than single projects. This aspect of the evaluation process upheld NJ TRANSIT's overriding objective—to increase trans-Hudson transit ridership and capacity.

RESULTS

Figure 4 lists the project rankings for each evaluation category and a list of the combined categories weighted equally. Characteristics of projects in each list are summarized as follows.

Financial Analysis

The projects that performed well have low incremental operating costs compared to the additional revenue generated, as

TABLE 2 WEIGHTS BY CATEGORY

Weighting Methods	Financial Analysis	User Benefits	Regional Impacts	Risk	Qualitative
1	1	1	1	1	1
2	2	1	1	1	1
3	1	2	1	1	1
4	1	1	2	1	1
5	1	1	1	2	1
6	1	1	1	1	2

FINANCIAL ANALYSIS	USER BENEFITS	REGIONAL IMPACTS	RISK	QUALITATIVE FACTORS
NJCL Expansion	West Shore - PSNY	Sec Trans/WS Trans	NEC Expansion	Sec Trans/WS Trans
NEC Expansion	NEC Expansion	Secaucus Connection	NJCL Expansion	Secaucus Transfer
Bay St Connection	West Shore Transfer	West Shore - PSNY	Kearny Connection	West Shore Transfer
Kearny/Bay Street	Secaucus Connection	Secaucus Transfer	Kearny/Bay Street	Secaucus Connection
Kearny Connection	NJCL Expansion	West Shore Transfer	Manhattan Transfer	West Shore - PSNY
Secaucus Connection	Sec Trans/WS Trans	NEC Expansion	Bay St Connection	Kearny/Bay Street
Red Bank to Lakewood	Kearny/Bay Street	Kearny/Bay Street	Red Bank to Lakewood	Kearny Connection
NJCL Dual Mode	Rar Valley Dual Mode	NJCL Expansion	Old Bridge Extension	West Shore to Hoboken
Amboy to Lakewood	Kearny Connection	West Shore to Hoboken	Rar Valley Dual Mode	Bay St Connection
Manhattan Transfer	West Shore to Hoboken	Amboy to Lakewood	NJCL Dual Mode	Manhattan Transfer
Secaucus Transfer	Manhattan Transfer	Old Bridge Extension	West Shore to Hoboken	NEC Expansion
Old Bridge Extension	Secaucus Transfer	Kearny Connection	West Shore Transfer	NJCL Dual Mode
West Shore - PSNY	NJCL Dual Mode	Manhattan Transfer	Secaucus Transfer	Rar Valley Dual Mode
Sec Trans/WS Trans	Red Bank to Lakewood	Rar Valley Dual Mode	Amboy to Lakewood	NJCL Expansion
West Shore Transfer	Bay St Connection	Red Bank to Lakewood	Sec Trans/WS Trans	Old Bridge Extension
West Shore to Hoboken	Amboy to Lakewood	NJCL Dual Model	West Shore - PSNY	Red Bank to Lakewood
Rar Valley Dual Mode	Old Bridge Extension	Bay St Connection	Secaucus Connection	Amboy to Lakewood

FIVE CATEGORIES WEIGHTED EQUALLY

NEC Expansion
NJCL Expansion
Kearny/Bay Street
Sec Trans/WS Trans
West Shore - PSNY
Secaucus Connection
West Shore Transfer
Secaucus Transfer
Kearny Connnection
Bay St Connection
Manhattan Transfer
West Shore to Hoboken
Red Bank to Lakewood
NJCL Dual Mode
Rar Valley Dual Mode
Amboy to Lakewood
Old Bridge Extension

FIGURE 4 Evaluation criteria project ranking.

well as relatively low capital costs. The poor performers had either very high capital costs without a good rate of return on the capital investment, or created large incremental increases in the operating costs of the railroad.

User Benefits

The highest-ranking projects have strong potential to attract new riders as well as benefit a large proportion of existing riders, improve corridor travel times, and reduce the transfer burden.

Regional Impacts

The strong performers in this category create relatively large auto diversions, improve the transit market share in the region, and accommodate projected growth in the region. Poor performers primarily benefit existing riders rather than new riders and, therefore, have little regional impact.

Risk

The least risky projects are those that would be easiest to implement considering operations, construction, and potential external barriers.

Qualitative Factors

The high-performing projects provide interconnectivity among the rail lines to allow for greater intra-New Jersey mobility, provide transit service in growing development and redeveloping areas in northern New Jersey such as Newark, the Meadowlands, and the Waterfront, and provide a transit alternative to the northern suburbs that currently rely heavily on autos for trans-Hudson travel.

Combination of Five Categories

When all five categories were weighted equally the project ranking was as follows:

- Northeast Corridor Expansion
- North Jersey Coast Line Expansion
- Kearny Connection and Bay Street Connection at Montclair (combined project)
- Secaucus Transfer and West Shore Transfer (combined project)
- West Shore Connection to New York Penn Station
- Secaucus Connection
- West Shore Transfer
- Secaucus Transfer
- Kearny Connection
- Bay Street Connection

- Manhattan Transfer
- West Shore to Hoboken
- Red Bank to Lakewood
- NJCL Dual Mode
- Raritan Valley Dual Mode
- Amboy to Lakewood
- Old Bridge Extension

The four projects that topped this list became the NJ TRANSIT staff recommendation known as the "preferred package" of projects. This group of projects has relatively low risk, performs well financially, addresses policy concerns, benefits a large proportion of riders, and penetrates markets where transit usage is currently low. The prerequisite for these projects is the upgrading of rail system capacity to New York Penn Station.

Three of the projects in the preferred package were the top ranking financial projects, but the Secaucus Transfer/West Shore Transfer project was also included. While this combined project did not rank high financially, it was strong in the regional impacts/qualitative factors categories and performed above average in the user benefits category. The project that ranked the highest in user benefits, West Shore Connection to New York Penn Station, was not included in the preferred package because of its high capital costs and high risk factors. For similar reasons two projects that ranked high on regional impacts, Secaucus Connection and West Shore Connection to New York Penn Station, were eliminated from the preferred package. The selected projects are all low risk except the Secaucus Transfer/West Shore Transfer project, which is lower in risk than the competing options in the North Jersey/Bergen County area.

Sensitivity Analysis

Various weighting methods were conducted to test the stability of the project ranking. The different weighting patterns enabled the evaluation process to consider the differing outlooks that might be adopted by decision-makers. For example, a fiscal conservative might consider the financial analysis category as crucial, while a more service-oriented person might look at the user benefits category, or a cautious person might concentrate on risk.

This sensitivity analysis indicated that there was stability in the top-ranking projects if viewed from different perspectives, especially for the two service expansion projects (Northeast Corridor and North Jersey Coast Line) and the Kearny/Bay Street Connection combination project. Weighting regional impacts, risk, and qualitative factors twice keeps the same preferred package of projects at the top of the list. The ranking changes that occurred when the financial analysis and user benefits categories were weighted by two involved the Secaucus Transfer/West Shore Transfer combined project and either the Secaucus Connection or West Shore Connection to New York Penn Station. Both the connection projects present significant risks to NJ TRANSIT because of the more complex engineering required to construct them, compared to their transfer alternatives and because both require dual-mode locomotives to operate.

NJ TRANSIT is particularly concerned about choosing any option that requires dual-mode locomotives. Currently, no dual-mode equipment that meets NJ TRANSIT requirements exists. Moreover, the New York City Fire Department has objected to operating dual-mode equipment through the tunnels under the Hudson River (diesel locomotives are currently prohibited from operating in the tunnels and in New York Penn Station). NJ TRANSIT is currently developing a prototype locomotive, but until it has been tested and accepted, NJ TRANSIT does not want its planning program to depend on the unknown technology of dual-mode locomotives. If the projects requiring dual-mode locomotives were eliminated from the project list, the preferred package of projects comes out at the top of the ranking for all six weighting scenarios.

To test the importance of the qualitative criteria in the evaluation process, rankings were prepared based only on the quantitative criteria. West Shore Connection to New York Penn Station and Secaucus Connection again rose to the top of the list, replacing the two combination projects. The effect of considering projects in combination was also tested. When only the 15 individual projects were ranked, the Secaucus Connection and West Shore Connection projects performed better than the individual Secaucus Transfer and West Shore Transfer projects in all the weighting schemes that double-weighted the quantitative criteria categories (financial, user benefits, regional impacts). If either the risk or qualitative categories were weighted by two the individual projects, Secaucus Transfer and West Shore Transfer, did rank above the two alternative connection options. These tests indicated the importance of the qualitative criteria in NJ TRANSIT's decision making process.

One final note—the three Monmouth/Ocean options appeared on the bottom half of the ranking list for all of the weighting schemes. Nevertheless, a Monmouth/Ocean option is considered by NJ TRANSIT as worth advancing to address overall needs in each of New Jersey's transit corridors and to prepare to handle a rapidly expanding market.

NJ TRANSIT EVALUATION RESULTS COMPARED TO PRIVATE SECTOR DECISION-MAKING

It is worth examining the results achieved through NJ TRANSIT's evaluation process compared to what might have resulted if a strict adoption of private sector cost/benefit analysis were followed.

The private sector relies on measures that compare the revenue generated by a project over its proposed life to the costs of the project to determine whether it will yield a net positive gain for the investor. Measures commonly used for this analysis include net present value, return on investment, internal rate of return, and payback period. NJ TRANSIT incorporated two of these indicators into its evaluation process—net present value and return on investment. Net present value is generally held to be the method that provides the best ranking of capital investments (*5*). As H. Wohl and C. Hendrickson state in *Transportation Investment and Pricing Principles* (*6*): "Economists almost universally find the net present value method superior to all others, both because it is simple and because it is unambiguous in indicating which alternative has the highest economic potential."

Not surprisingly for public transit projects, none of the projects considered by NJ TRANSIT produced a positive cash flow; all would have been rejected in a strict private sector analysis. The project ranking produced by the net present value analysis differed substantially from rankings that included the combination of criteria. As revenues could not offset capital costs, the projects that ranked the highest for net present value tended to be those that were low in capital costs, i.e., "small" projects. Two of the NJ TRANSIT preferred projects—the service expansion projects on the North Jersey Coast Line and Northeast Corridor—did rank second and fourth respectively on the net present value ranking. These are both low capital cost projects.

The return on investment ranking produced a somewhat different project ordering. Projects that had significant ridership growth (and therefore generated revenue) ranked higher than they had on the net present value ranking. Three of the NJ TRANSIT preferred projects—North Jersey Coast Line Expansion, Northeast Corridor Expansion, and Kearny/Bay Street—were ranked one, three, and four respectively.

Of the projects chosen by NJ TRANSIT, the Secaucus Transfer/West Shore Transfer, which appeared on the bottom half of both lists, had the greatest regional impact and strongest ridership draw. If this project had not been chosen, the regional transportation problem of trans-Hudson travel congestion would not have been completely solved, nor would NJ TRANSIT's objective in investing in the transportation system have been achieved.

This comparison highlights two important points. First, since public transit projects are not profitable and do not pass the threshold criteria for private investment endorsement, other public policy factors *must* be considered. Second, these other public policy factors can be pivotal in the decision-making process.

CONCLUSION

It is clear that the qualitative factors selected by NJ TRANSIT played a significant part in shaping the final decision. NJ TRANSIT was unwilling to ignore the risk elements involved in actually constructing and operating a project. In addition, economic growth and development in New Jersey made it imperative for NJ TRANSIT to consider the broader impact of transportation investments on the regional economy.

The evaluation and analysis process undertaken indicates that the projects selected are strong performers, especially if a strategy of avoiding unnecessary risk is adopted. The evaluation process was conceptually simple, an attribute which helped decision-makers learn the results of technical analyses in a way they were able to use.

Examining the projects from different perspectives (financial, risk, etc.) raised issues that were important to discuss before decisions could be made. Introducing qualitative factors into a framework allowed them to be combined with harder quantitative data, which enabled the projects to be evaluated objectively, from a broad perspective. The ability to demonstrate stability among the rank order of projects under different weighting scenarios was particularly useful in the decision-making process. The projects selected represent a good choice both from an economic viewpoint, and in terms of the transportation benefits they bestow on the region.

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Three-Step Operations Planning Procedure for Transit Corridor Alternatives Analyses

GREGORY P. BENZ

This paper briefly describes the UMTA transit project planning process and outlines the role that operations planning plays in alternatives analyses (AAs) conducted under the Urban Mass Transportation Administration's (UMTA's) Urban Mass Transportation Major Capital Investment Policy. Operations planning provides input essential for defining alternatives, patronage forecasting, operations and maintenance cost estimating, capital-cost estimating, and environmental impact assessments. Despite its critical role, operations planning is given little attention in UMTA's latest guidance of alternatives analyses—*Procedures and Technical Methods for Transit Project Planning*. A discussion of operations planning issues often encountered during the AA is provided, and a three-step operations planning process for transit corridor alternatives analyses is described. A discussion on the role that computer models can play in operations planning concludes the paper.

Over the past decade, requests for federal support for new fixed-guideway transit projects in urban areas throughout the country have far outstripped the funds available. Not only has the number of projects increased, but the size and cost of the projects have grown as well. Unable to meet all demands for funds, the Urban Mass Transportation Administration (UMTA) has established a framework of policies and procedures to evaluate competing projects. The process, most recently spelled out in UMTA's May 1984 Urban Mass Transportation Major Capital Investment Policy, outlines the five steps for project development, as shown in Figure 1 (*1*).

The systems planning step leads to identification of the existing and future transportation problems to be addressed, the transportation corridor that has the most serious problems to be solved, and a set of potentially cost-effective, fixed-guideway alternatives to address the problems. The second step involves detailed planning evaluation of a set of transit alternatives, called the alternatives analysis/draft environmental impact statement (AA/DEIS) step. Following this step, an alternative is chosen, followed by the design and construction stages. UMTA concurrence and approval are required to advance to each stage after systems planning, presuming after each stage, that the locality wishes to remain eligible for federal funds.

To evaluate each candidate project using comparably developed data, UMTA has developed documentation providing technical guidance on the procedures used during the alternatives analysis and evaluation. The latest edition (review draft) of these guidelines, entitled *Procedures and Technical Methods for Transit Project Planning* was issued in September 1986 (*2*). This document builds on previous editions and provides a set of well-established procedures which focus on areas generally considered to have greatest influence on the outcome of the alternatives analysis—alternatives definition, demand forecasting, operations and maintenance (O&M), capital-cost estimating, and alternatives evaluation. Operations planning, however, is given very little attention in the UMTA guidelines while O&M cost-estimating procedures, which depend entirely on input derived from the operations planning steps, are specified in great detail; the document devotes 23 pages (an entire chapter) to O&M cost estimating.

OPERATIONS PLANNING FOR AAs

Operations planning involves identification and analysis of the movement of passengers and vehicles along routes, frequency and coverage of service, station/stop locations, travel speeds and running times, and the estimation of various operational data. Operations planning analysis provides important input to several key areas:

- Alternatives definition—identification of routes, service types (express, local), types of vehicles, transfers and fare policies, feeder/distribution systems, and other policies and characteristics that make up the various alternatives;
- Demand forecasting—estimation of travel times, service frequency, average waiting times, and other inputs to the demand forecasting process and the balancing of travel demand and service capacity (equilibration);
- Operations and maintenance cost estimation—determination of various operating statistics, such as vehicle miles or platform hours, for example, as inputs to the cost modeling.
- Capital cost estimation—determination of vehicle fleet size and the needed maintenance facilities as well as any special physical facilities required to allow the vehicles and passengers to move in the manner desired.
- Environmental impact assessment—the identification of factors such as frequency and speed of vehicles which may affect noise levels, air quality, and energy consumption, and consequently require mitigating measures that add to the capital costs (such as noise barriers) or impose operating restrictions (speed reductions) on the various alternatives.

CONSIDERATIONS IN AA OPERATIONS PLANNING

The operations planning process must address numerous issues, such as demonstrating the operational feasibility of the bus

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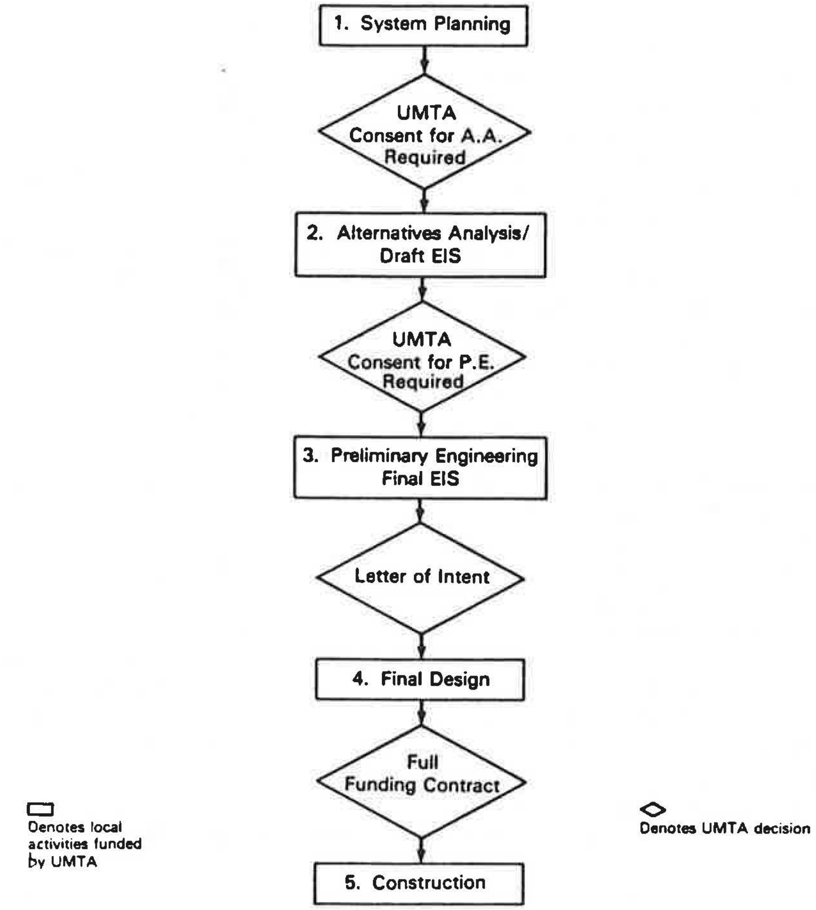

FIGURE 1 **UMTA project development process (*1*).**

and rail alternatives; other issues involve features peculiar to the bus and rail modes under consideration. Still others involve the need to provide comparable data for evaluating alternatives under the UMTA guidelines. The following discussion is not exhaustive, but illustrates some of the more important issues.

Transit supply (frequency of service, capacity) should match passenger demand. Initial service levels assumed for each alternative or subalternative will attract a certain passenger demand, which must then be compared to the available capacity of the alternative at the initial service level assumed. Frequency of service is adjusted to provide the proper service level, although the range of headways is bounded by safe operating practices for particular modes at one end, and policies on minimum levels of service at the other end, and must take into account current and future bus and rail operations. Changes in initial headway assumptions used in the patronage projections will result in shifting demand; a change in demand, in turn, causes a change in headways. This balancing, or equilibration, of supply and demand is essential in refining the definition of the alternatives.

The operations plan, particularly for the bus alternatives, should consider service subalternatives such as routing variations (skip-stop, branching, express services) or policy/operational variations (on-board fare collection, self-service fare collection, policies regarding elderly and handicapped passengers). Compatibility with current operating practices elsewhere in the corridor, however, is important, and the extent to which current and future services are integrated must be determined at policy and operational levels.

Estimates of travel times and headways should be realistic, recognizing the physical and operational constraints of the alternatives and their alignments. Headways should be achievable and maintainable, taking into account traffic patterns and congestion, transit travel speeds based on traffic/parking regulation enforcement, safe operating standards, vehicle availability, turnaround time at the terminals, and signal system capacity.

Transportation system management (TSM) actions can result in changed operations for current or future transit lines that can influence travel times, operating speeds, vehicle miles, vehicle hours, and other measures. Operations planning must estimate the level of improvement that will result from implementing TSM actions for the bus alternatives and the feeder bus component of the rail transit alternatives.

Assumed operating practices and standards, particularly standee comfort levels on vehicles, must enable bus and rail alternatives to be compared. However, these standards and practices must recognize the particular features of each modal alternative and allow them to be emphasized where possible.

A critical consideration for rail transit alternatives is the relationship between operations planning and the engineering/capital-cost-estimating at the terminal stations. Operationally, a terminal must be able to accommodate the reversal of train directions, and possible crew shifts, train layovers, and storage of bad-order trains and maintenance vehicles. The signal and control system and the location of crossovers or tail tracks will influence the turnaround time at the end of the line, which in turn may affect desired peak-period headways or increase vehicle and crew requirements. Because of the cost of underground construction and potential constraints, the operations at subsurface terminal stations must be carefully analyzed to avoid unnecessary expense. At the same time, however, capital expenditures must be balanced with long-range operating costs, as well as the goal of efficient and flexible operations. In addition, it is possible that the station may be an interim terminal, if a line is built incrementally. Constructing crossovers and other elements at the interim terminal, which may not be needed once the line is extended, may sink resources into features which would have relatively short useful lives. Thus, the terminal operations, especially at interim locations, must be carefully integrated with both operating policies and plans for the rail system and the engineering and capital-cost analysis. The potential for interface problems at terminals with feeder bus routes, park-and-ride lots, pedestrian circulation, and spillover parking into residential areas also needs careful consideration.

Current transit service in the study corridor will be altered with the introduction of one of the "build" alternatives. Feeder services to a new line-haul system will be created by rerouting existing services or instituting new routes. Much of the line-haul service patronage usually comes from bus services on or near the new alignment. Thus, some of the present bus service can be reduced because of the shift of passengers, although trips not accommodated by the new services may continue to be provided. The potential reduction in background bus service needs means that resources (vehicles, personnel, etc.) can be applied to new feeder services or converted into operating cost savings.

THREE-STEP OPERATIONS PLANNING PROCESS

A three-step operations planning process—applicable to most transit corridor studies—has been developed and refined in several UMTA-sponsored projects: originally in the Baltimore North Corridor and recently in the Milwaukee Northwest Corridor and Baltimore Northeast Corridor. The process presented here does not depart dramatically from current practice but formally presents ideas and procedures which have evolved from previous technical guidance (*3*) and discussions among the participants in these studies—transit and planning agencies, consultants, and UMTA. Briefly, the three steps are as follows (Figure 2):

Step One: Develop operating and service policies and standards, including characteristics of the vehicles to be used for operations planning purposes.

Step Two: Prepare initial operations plans to supply input to demand forecasting: network data, station-to-station travel times, access linkages, headways, and transfers. These should reflect operating characteristics of the modes and the alignment/right-of-way.

Step Three: Develop detailed operating plans. Following initial patronage results, an "equilibration" process is conducted in which transit demand (peak-load points) and supply (headways, capacities) are balanced. Then, detailed operating characteristics and statistics are prepared for input to the operating and maintenance cost estimates, capital-cost estimates (vehicle fleet size and storage/maintenance facilities), and environmental impacts/mitigation measures.

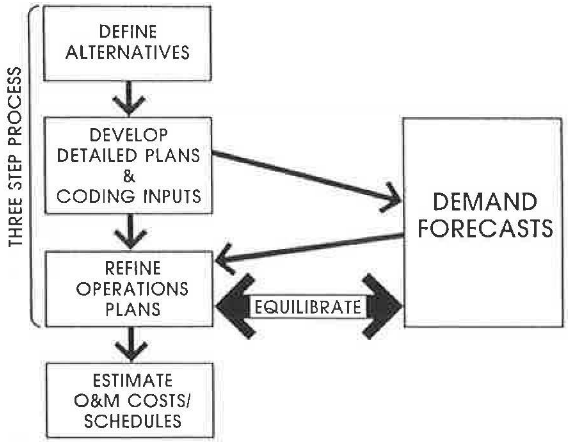

FIGURE 2 Three-step operations planning process.

The three steps in the process are described in more detail in the following paragraphs.

Step One Operating Plan

This step develops the initial assumptions and major operating philosophies and concepts for modal alternatives proposed for the transit corridor. They are arrived at through examination of travel patterns in the corridor, passenger demand levels estimated in earlier studies of the corridor (if any), results of previous transit improvements in other parts of the region, and the experiences of similar corridors in other cities. In addition, the policies and constraints of present transit operations in the corridor are major factors in developing the Step One Plan. Typically, this effort involves extensive interaction among the planning and operating staffs of the transit properties operating or planning to operate in the corridor, and the study planners.

The Step One Plan should reflect relevant results of the AA/DEIS Scoping Process and begin concurrently with alternatives definition. The plan also serves as the starting point for the patronage forecast and engineering efforts. For each modal alternative, operating assumptions, philosophy, and concepts are established to include the following items:

- nature of line-haul service
- collection/distribution service (feeder bus, park-and-ride lots)
- fare collection method/policy
- initial headway assumptions by time of day
- operating environment
- equipment type
- integration with existing transit operations
- labor policies
- station policies
- elderly and handicapped accessibility (Section 504) policies

For many alternatives much of this information will be similar, although some items such as access mode concepts may differ because of site constraints and potential impacts. Some policies could be assumed to be constant for all alternatives. For example, it could be assumed that the desired size of area per standee, and associated comfort level, may be relatively consistent across all modes, but may vary with trip distance and duration, and the operating environment.

As a rule, many of these policies have already been established by the operating authorities/properties serving the corridor or region.

In addition to the items just discussed, it is useful to document the characteristics of the vehicles which would likely be used, or at least used for purposes of the study. Generally, bus and rail transit vehicles which are already (or soon to be) part of the transit system are used. Vehicle characteristics should be based on recent or future procurements, as well as on information from vehicle manufacturers. The characteristics of various bus types, such as articulated buses, might also be included if they are not already in the fleet, since they may offer operating and capital-cost savings on high-volume routes.

The following types of information should be included in the list of the vehicle characteristics: vehicle dimensions and capacities (seated and standing), performance and operating characteristics (energy consumption, maximum speeds, acceleration/deceleration rates), operating and maintenance costs, market conditions such as availability and delivery times, purchase price, usable life expectancy (replacement cycle), spare ratios, environmental specifications (noise and emissions levels), and elderly and handicapped accessibility features. Table 1 shows an example of typical bus characteristics.

Where a vehicle type or mode not currently used in the region is considered, or where there is a range of vehicle

TABLE 1 EXAMPLE OF TYPICAL BUS CHARACTERISTICS (*4*)

	Articulated	Conventional
Dimensions		
Length	60'	40'
Width	102"	102"
Height	129"	120"
Overhang		
- Front	108"	91"
- Rear	106"	90"
Turning Radius:		
- Outside	40'	44'
- Inside	20'	37'
Entrance Steps		
- From Ground	15"	13"
Exit Steps		
- From Ground	15"	16"
Door Clear Opening		
- Front	48"	30"
- Rear	48"	44"
Aisle Width	17"	16"
Curb Weight	37,500 lbs.	26,000 lbs.
Approach Angle	8°	10°
Breakover Angle	7.5°	10°
Departure Angle	8°	9.5°
Passenger Accommodation		
Capacity		
- Seated	64	40
- Standing	32	20
Total	96	60
Performance		
Acceleration (mph/sec.)		
0-10 mph	3.1	3.33
10-30 mph	1.5	2.22
30-50 mph	0.75	0.95
Top Speed (mph)	65	65
Normal Deceleration (mph/sec.)	2-3	2-3 average
Fuel Consumption (miles/gallon)	2.5	4 Average

characteristics from "off-the-shelf" vehicles, such as light rail vehicles, it is useful to develop a "composite" vehicle. For some characteristics, such as physical dimensions, the most limiting or largest factors, such as lateral and horizontal clearances and turning radii, should be used for physical design tasks. In this way, the widest range of vehicle types can be accommodated and no particular vehicle model or manufacturer is precluded at this early planning phase. For other characteristics, such as acceleration and deceleration rates, maximum speeds, and passenger capacities, it is appropriate to use average or most likely values.

The vehicle characteristics data are used in the three-step operations planning process as well as in the engineering, capital, and operations and maintenance cost estimating, and environmental analysis tasks.

Step Two Operating Plan

This step results in detailed operating characteristics for each alternative. Besides elaborating on the operating assumptions and concepts presented in the Step One Plan, it develops network coding input to the patronage forecasting task.

The initial alternative concepts are translated into specific configurations of line-haul, feeder, and distribution services in the corridor and the central business district (if the corridor is oriented toward one), with corresponding descriptive data. Descriptions will include relevant physical characteristics from the alternatives definition and engineering tasks—alignment (horizontal and vertical), routing, vehicles, and operational features, as well as descriptions of service function, coverage, accessibility, connectivity (or transferability to current services), and service performance. Specific detailed characteristics for patronage analysis include initial headways for peak and nonpeak periods, travel times (from link speeds, dwell times, access times, etc.), and network configurations. Travel-time data for routes can be developed using established schedules, field speed runs (actual time and speed measurements), operator's data, and calculations using standard speed/distance formulas.

Microcomputers can store the data using an electronic spreadsheet program such as Lotus 1-2-3. Besides enabling systematic storage and retrieval, the microcomputer makes it easy to revise, modify, and conduct sensitivity testing.

The travel time for alternatives introducing new modes or routes is developed in similar fashion. If the alternative extends current systems, this information can be developed in close coordination with the systems' operating staffs, especially at the terminal stations.

Step Three Operating Plan

This step follows the development of initial patronage projections for each alternative. It consists of three elements: equilibration of transit supply and demand; development of detailed operations plans, characteristics, and statistics; and preparation of annual operating statistics, personnel requirements, and energy consumption.

Equilibration of Supply and Demand and Refinement of Alternatives

The first effort in Step Three is refining the alternatives by balancing the transit supply (frequency of service, vehicle capacity) and passenger demand. Patronage projections, which are based on information in the Step Two Operating Plan, include such factors as assumed headways for initial service planning. Once the initial patronage projections are available, the alternatives are refined, if appropriate, to adjust capacity, service, and facility elements.

The number of peak-period transit-vehicle departures on the line-haul service required by the forecasted demand is compared with the original assumption on departures and frequency of service. If the revised frequency varies significantly from the original assumption, then the patronage estimates are adjusted by rerunning the demand forecast model iteratively until the supply and demand are balanced. Another less costly approach is to use an elasticity-based procedure where the change in frequency of service causes a change in ridership based on the specific elasticity factor used. If the capacity is too much or too little after the first try, the process will be repeated until a balance is achieved. Experience has shown that the balancing generally occurs within two iterations of this process. The final headway must fall within the limits of safe operating practices, the property's operating plans and policies, and minimum levels of service (maximum headway). The equilibration is performed for the peak (high-demand) periods only; nonpeak-period headways generally are based on policy decisions. Table 2 shows the results of an equilibration step. Other refinements may include adjustments to dwell times due to station/stop loadings, and elimination or adjustment of certain components of the alternatives (such as parking facilities) for cost, use, or environmental reasons.

Detailed Operations Plans Characteristics and Statistics

The detailed operating characteristics and statistics of each alternative and subalternative are developed for each service or route in the alternative. Trip times and distances are available from the Step Two plan. Recovery and layover or turnaround times are added. Headways are taken from the equilibration and refinement results. Using trip times and headways throughout the day for the various services and trip distances, vehicle requirements (by time of day), vehicle miles, vehicle hours, vehicle trips, and related statistics are developed for a typical weekday. Related statistics include car miles and hours, and train consists (where relevant) as well as place miles and hours. These statistics must recognize two-way trips, one-way trips, deadheading, and other operating features. Access modes are treated in similar, although possibly more aggregate, manner. Reductions in background bus services can be estimated based on the number of bus riders who would shift to the alternative and the current bus service levels. The resulting operations plans are compared with similar transit operations for validity, including checks such as average speed, load factors, and revenue miles to total miles.

For rail transit alternatives, the configuration of the terminal is often a key factor in determining the capacity of the proposed line. If the proposed line is an extension of a current

TABLE 2 EXAMPLE OF EQUILIBRATION OF SUMMARY SHEET (*4*): BUSWAY ALTERNATIVE—AM PEAK

		Original		Revised		
Service	Inbound/ Outbound	Headway (Minutes)	Demand (Pass.)	Headway (Minutes)	Demand (Pass.)	%*
Hunt Valley Express	I	15	321	15	321	0
Hunt Valley Express	O	15	147	15	147	--
Warren Road	I	15	329	15	329	0
Warren Road	O	15	24	30	23	-4.2
Padonia	I	30	156	30	156	0
Padonia	O	30	19	No Service		--
Spring Lake	I	10	444	12	425	-4.3
Spring Lake	O	10	47	30	46	-2.2
Providence Road	I	20	125	30	114	-4.3
Providence Road	O	20	10	No Service		--
Dulaney Valley	I	15	444	10	499	+12.4
Dulaney Valley	O	15	204	20	201	-1.3
GBMC/Towson State/ Towsontowne	I	20	240	20	240	0
GBMC/Towson State/ Towsontowne	O	20	176	20	176	0
York Road	I	10	625	8	654	+4.7
York Road	O	--	0	No Service		--
Hunt Valley Local	I	2	2875**	2	2875**	0
Hunt Valley Local	O	2	481**	2	481**	0

*Percent change of revised demand from original forecast.
**Peak Line Volume north of MetroCenter.

line, capacity of that line will be affected as well. Signal timings, speed restrictions for curves, crossovers, and turnouts, dwell times, and vehicle acceleration and deceleration rates for the current line are used to calculate the time required to turn trains. Also, possible requirements for laying up trains and providing trackage for turnback service, emergency use, and maintenance-of-way equipment are examined. Operational requirements for track work and signals are determined and used as input to the engineering task.

In addition, the relationship between line-haul and feeder service operations at the terminals should be examined in light of peak-period travel demand. This information is used to provide pedestrian flow data for use in station design and feeder bus, park-and-ride, and kiss-and-ride facilities.

Preparation of Annual Operating Statistics

The statistics and characteristics of each alternative, including access modes must be summarized and documented. Daily statistics for each alternative are converted into annual statistics, energy consumption is estimated, personnel needs are projected, and total vehicle requirements (including spares) derived. Annualization factors are based on data obtained from services or derived from number of holidays, weekends, and full work days. Generally, the annualization factor for service operations should be slightly higher than the annualization factor for ridership. Energy consumption is based on the vehicle type, average speed, vehicle miles, and operating experience in the study area as well as areas with similar

TABLE 3 EXAMPLE OF STEP THREE SUMMARY SHEET (*4*): 1995 NORTH CORRIDOR ANNUAL TRANSIT STATISTICS AND VEHICLE REQUIREMENTS

	Vehicle Miles		Vehicle Hours		Peak Vehicle Requirements		Vehicle Fleet Requirements	
	Bus	Rail	Bus	Rail	Bus	Rail	Bus	Rail
1995 North Corridor Base	11,908,252	-	893,601	-	319	-	407	-
Baseline	12,449,903	-	911,416	-	334	-	426	-
Express Bus Park'n'Ride/TSM	13,361,242	-	949,951	-	363	-	460	-
Busway	16,288,242	-	1,066,172	-	453	-	570	-
Commuter Rail	12,237,806	546,000	942,247	21,600	351	12	426	14
Rail Transit								
- Towson Mainline	11,838,568	1,366,200	841,730	45,900	308	27	392	32
- Ruxton Mainline	11,846,256	1,209,300	846,325	41,400	309	24	393	29
- Baltimore St. At-Grade	11,319,559	1,338,000	802,783	50,400	294	30	375	36
- Redwood St. At-Grade	11,847,714	1,273,000	842,416	42,000	314	27	399	32

operating environments. Personnel needs are estimated using a labor buildup approach, considering local experience and practices as well as those of other areas, recognizing that the many proposed alternatives are generally expansions of present systems.

The information developed in this step for each of the alternatives, subalternatives, and variations is assembled for presentation in summary form—an example of which is shown in Table 3. This information supplies input to alternatives refinement, engineering, environmental analysis, and capital and operations and maintenance cost estimating. Generally, a Step Three Operating Plan technical memorandum forms the basis of a Final Operations Plan Report, which will include relevant portions of Step One and Step Two Technical Memoranda and a Vehicle Characteristics Report. Appendices provide backup data. The report is prepared so that key portions can be readily inserted into the AA/DEIS document with minimal reformatting and rewriting.

USE OF COMPUTER OPERATIONS PLANNING MODELS

Keeping track of changes to a large number of transit routes and services—changes in headways, vehicle hours, platform hours—can be quite complex, especially when several alternatives are being considered. Various computer-based tools are available to help with this task.

Some regional transportation planning models used for travel demand analyses, such as UMTA/FHWA's Urban Transportation Planning System (UTPS), include components that deal with transit operations. UTPS's Integrated Transit Network program (INET) (*4*) can be used to compute the operating statistics for the entire transit system, including keeping track of statistics by various modes, lines, operating divisions, or companies. There are now PC-based programs available with similar capabilities.

Operations simulation models can also be used; however, these models are geared to single-mode systems, such as a rail line or people mover system, and often focus on propulsion power requirements. Modeling the entire transit system, including feeder and background bus network, is either not possible or cumbersome at best.

These types of models are often expensive to use—both in terms of labor to prepare input data and computer time. Often, PC-based spreadsheet programs can be effective tools for operation analysis. One attribute of PC-based programs is that the consequences of changes to individual routes and services are very visible to the analyst. Sensitivity testing is relatively easy, quick, and inexpensive.

SUMMARY

Operations planning is an important part of transit corridor alternatives analysis which is not adequately addressed in current UMTA technical guidelines. The three-step operations planning process described provides a structure that is integrated into the recommended overall analytical work flow.

The three-step planning process as applied in the Baltimore North Corridor alternatives analysis (*5*) was described in a state-of-the-art review on operations planning as follows (*6*):

> Recent transit guideway planning has also included significantly greater effort for the development of operating plans. One study (Baltimore North Corridor AA/DEIS) structured a three-stage process for plan development that proceeded from a conceptual definition through an initial detailed specification to a final plan that was revised and refined to match the patronage levels and travel patterns in the corridor. The final operating plan for the busway included a mix of express services focused on the center city and local busway services stopping at busway stations served by feeder buses. The process significantly increased the reliability of the service, patronage, and cost estimates in that it ensured that these estimates reflect an appropriate, efficient operating scheme for the facility.

The three-step process has since been applied to numerous AAs with comparable success. Where it has been included in the work scope for AA/DEISs, operations planning has been properly incorporated into the study process. In studies where operations planning has not been explicitly treated, operational issues and factors have been given insufficient attention, especially in defining and refining the TSM and bus alternatives. The three-step process provides a structure to address operating policies and issues early in the study, which is vital to developing alternatives that address the problems to be solved in the corridor.

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Design of Public Transport Networks

ROB VAN NES, RUDI HAMERSLAG, AND BEN H. IMMERS

This paper describes the major features of an optimization model which can be used to design public transport networks. Design problems that can be solved with the model involve the redesign of either a part of a network or a complete network and the assignment of frequencies. The model consists of an additive procedure in which the decision to incorporate a route in the network or to increase the frequency of a route is based on an economic criterion which can also be regarded as an estimate of the Lagrange Multiplier of the optimization problem. A major advantage of the model is that the different design problems are solved with one single optimization process. Furthermore, the optimization process is kept understandable and the model is suited for use on a personal computer. Some results of the model are presented.

Due to the changing economic situation the financial constraints of public transport have become more and more important. The government is no longer willing to account for all deficits of the public transport companies. The policy has changed into granting a single subsidy with which the public transport companies have to offer service which can compete with other modes and transport facilities for those who cannot travel otherwise. Since the subsidy will be limited, the public transport companies will have to reconsider the service they are offering. Of course, it is also necessary to cut costs by improving the scheduling of personnel and vehicles, as well as the regularity of the service.

The design of the network deserves extra attention, as it is the network that determines the service offered. Moreover, the network is used as input for studies concerning other aspects such as timetables, scheduling, and regularity. Another reason for extra attention to the design of public transport networks is the fact that networks have often been adjusted by using simple design methods to meet changes in the city, e.g., new residential areas. Very little use was made of sophisticated tools such as traffic forecasting and assignment models. See for instance Chua and Sitcock (*1*) for a survey of planning techniques used in Great Britain.

The problem of the network design can be formulated as follows: which routes and which frequencies should be offered to fulfil the demand for public transport as well as possible, given a certain available budget.

EXISTING DESIGN METHODS

The type of model mostly used for network design is an evaluation model in which an origin-destination (OD) matrix is assigned to a network and with which all kinds of evaluation characteristics are calculated. Such an evaluation model enables a systematic comparison between alternative network designs. Although the use of evaluation models must be considered as a major improvement to the quality of the planning process, the disadvantage remains that only a few alternatives can be compared because of the effort involved. Also, these alternatives will often be biased towards the existing network and the implicit ideas of the planner, although in some cases this might be considered as an advantage.

The disadvantage of a limited number of alternatives, however, does not apply to models which design a network as well as evaluate it. These so-called optimization models use operations research techniques to find a feasible network. The name optimization model is misleading, however, because most models do not find an optimum solution and even then it is questionable whether an optimum of a model, which is a mathematical description of reality, will be an optimum in reality. Therefore, the importance of these models does not derive from the fact that they find a (near) optimum solution, but rather that they help to find new and feasible alternatives.

Despite the advantage of generating new alternatives, the use of these optimization models is very limited. This limited use can be explained by several reasons, one of them being the overall lack of experience in using models in public transport studies, but when we take a close look at the optimization models which have been developed, some other reasons can be found.

EXISTING OPTIMIZATION MODELS

In the last two decades all kinds of optimization models for the design of public transport networks have been developed. These models can roughly be divided into six categories:

1. Analytical models (e.g., Holroyd [*2*], Kocur and Hendrickson [*3*]). These models use simplified networks to derive optimum relations for parameters of the public transport system, for instance headway and route-spacing.
2. Models determining which links should be used to construct routes for a public transport network (e.g., Billheimer and Gray [*4*], Rea [*5*]).
3. Models determining routes without considering the frequencies of the routes (e.g., Pierick and Wiegand [*6*], Simonis [*7*]).
4. Models assigning frequencies to a given set of routes

R. van Nes, Department of Civil Engineering, Delft University of Technology. Current affiliation: AGV Consulting Engineers. R. Hamerslag, Department of Civil Engineering and Department of Mathematics and Information Technology, Delft University of Technology. B.H. Immers, Department of Civil Engineering, Delft University of Technology, P.O. Box 5048, 2600 GA Delft, The Netherlands.

(e.g., Scheele [*8*], Furth and Wilson [*9*], Hagberg and Hasselström [*10*]).

5. Models determining routes in a first and assigning frequencies in a second stage (e.g., Lampkin and Saalmans [*11*], Dubois et al. [*12*]).
6. Models determining routes and frequencies simultaneously (Hasselström [*13*]).

The first two categories determine neither routes nor frequencies and are therefore unsuited for the problem we have formulated. The third and fourth categories solve only part of our problem, either routes or frequencies. Actually, there are only two categories of models suited to our design problem, categories 5 and 6.

Determining Routes and Assigning Frequencies Separately

The models of category 5 solve the network design problem in two stages. In the first stage the routes of the network are determined. The objective is to transport a maximum number of passengers given a fixed OD-matrix. In this stage Lampkin and Saalmans (*11*) consider trips without transfers, while Dubois et al. (*12*) consider all trips. In the second stage frequencies are assigned to the generated set of routes. The objective is to minimize the total travel time given the OD-matrix and the available number of vehicles. In the calculation of the travel time Dubois et al. (*12*) introduced the possibility of walking instead of using public transport. All the methods used are clearly heuristic, but those of Dubois et al. (*12*) are more sophisticated. The major disadvantage of these models, however, is the fact that they solve the problem of routes and frequencies separately, while there is a distinct relation between these two components of the public transport system. Moreover, a fixed OD-matrix is used, so the relation between supply and demand for public transport services is not taken into account.

Determining Routes and Assigning Frequencies Simultaneously

The model developed by Hasselström (*13*) does not have these disadvantages. It solves the problem in three stages. First, the model considers a link network and eliminates links seldom or never used by passengers (compare the models of category 2). The result is a concentrated network which is used in the second stage to generate a large set of possible routes. Finally, the route of the network are selected by assigning frequencies using linear programming. The objective is to maximize the number of transfers saved by changing from a link network (transfers at every node) to a public transport network (transfers only at intersections). Instead of a known OD-matrix, Hasselström (*13*) suggests the use of a desire matrix (i.e., an OD-matrix for the situation in which an ideal public transport system exists) in order to lessen the bias towards the network with which the OD-matrix is determined. The disadvantage of the model is that although routes and frequencies are determined simultaneously, two different optimization problems are formulated.

Use of Optimization Models

All optimization models discussed have rarely been used in practice. Most models have been employed only in the projects they were designed for, or in the tests described in the presentations. The model of Hasselström (*13*) forms part of the VOLVO-package, which contains a variety of models for planning public transport networks (e.g., Andréasson [*14*]), and has been used more often (Arnström [*15*], HTM [*16*] and Harris and Haywood [*17*]). The major disadvantages of all optimization models, however, are the complex structure (e.g., several optimization problems within one model) and the limited accessibility for planners as the models can be used only on a mainframe.

A NEW MODEL

The disparities between the capabilities of optimization models in the design process and the practical situation combined with the need to improve the design process are the reasons for developing a new model. If a model is to be used as a tool in the design process, it should fulfil the following requirements:

1. It should be suited for several design problems ranging from short-term analyses to long-term decisions, e.g., assigning frequencies, designing part of a network and designing a complete network,
2. It should be easily accessible and understandable for the user (i.e., the planner).

The model presented in this paper is an attempt to serve as such a model. It is suited for use on a personal computer and special attention is given to the interactive design process.

Moreover, the optimization model will be included in a software package for the design of public transport networks. This package will also contain a model for the determination of an OD-matrix, an evaluation, model and interactive programs to arrange the necessary input. Activities for which the package can be used are as follows:

1. Evaluating a network,
2. Assigning frequencies,
3. Designing or redesigning part of a network,
4. Designing or redesigning a complete network.

For activities 2, 3 and 4, the optimization model can be used. The optimization process is structured to be simple and understandable.

OPTIMIZATION PROBLEM IN WORDS

The main objective is to design a network which can fulfil the demand for public transport as well as possible. It is obvious that this objective cannot be used in an optimization model, as it is unclear what is meant by "as well as possible." Does a network qualify as "good" if it offers services which can compete with other modes, or if it is especially suited to the needs of people who cannot travel otherwise? The decision on what is meant by "as well as possible" is a political one, however, and should not be made within an optimization model.

An objective suited to an optimization model and for both interpretations of "as well as possible" is maximizing the number of passengers, given a certain budget. It is a well-known fact that transfers negatively affect the number of passengers. Recent research in the Netherlands shows a penalty of 6 minutes, not including the waiting time at the transfer point (Van der Waard et al. [*18*]). Therefore, maximizing the number of passengers is more or less equivalent to minimizing transfers, especially in middle-sized cities such as those in the Netherlands. Although minimizing transfers is a commonly used objective (see e.g., Hasselström [*13*]), it is preferable to maximize the number of direct trips. The objective of maximizing direct trips makes it possible to use a description in which the demand for public services depends on the quality of the services offered, while the objective of minimizing transfers requires a fixed OD-matrix. Therefore, we choose to maximize the number of direct trips.

The major constraint of the problem is the available budget. Since there is a strong relation between the available budget and the number of vehicles that can be put into operation, the optimization problem can be formulated as follows:

> Maximize the number of direct trips given a certain fleet size.

A special aspect of the public transport system is the use of different vehicle types (e.g., bus, tram). As the vehicle type influences both generalized costs and total costs, this aspect will also be included in the optimization model. Of course it is possible that, by maximizing the number of direct trips, networks may be developed which offer very poor transfer facilities, resulting in far fewer passengers than the highest number desirable. Therefore, additional constraints, such as a maximum number of routes or a minimum frequency, may be necessary. The decision as to which constraints must be imposed depends on the characteristics of the demand pattern and the specific network.

RELATION BETWEEN SUPPLY AND DEMAND FOR PUBLIC TRANSPORT SERVICES

The formulated objective makes it necessary to describe the relation between supply and demand for public transport services. It is not possible to use elasticities which are based on empirical research of the behavior of passengers as a result of changes in the public transport system. Usually these elasticities have constant values and are time and place dependent. Therefore, a direct demand model is formulated, which is based on the simultaneous distribution–modal split model (see, e.g., Wilson [*19*]). The relation between supply and demand for public transport is described by the deterrence function.

The simultaneous distribution–modal split model can be formulated as (see, e.g., Wilson [*19*]):

$$T_{ij} = r \cdot o_i \cdot d_j \cdot F_{ij} \qquad \forall i,j \tag{1}$$

where

T_{ij} = number of trips between nodes i and j,
r = constant term
o_i = factor for the generation of node i,
d_j = factor for the attraction of node j,
F_{ij} = value of the deterrence function for all modes for OD-pair i-j.

Constrained by:

$$\sum_{i} T_{ij} = D_j \qquad \forall j \quad \text{and} \quad \sum_{j} T_{ij} = o_i \qquad \forall i \tag{2}$$

where

D_j = arrivals at zone j,
O_i = departures from zone i.

F_{ij} can be written as:

$$F_{ij} = \sum_{v} [F_v(C_{ijv})] \qquad \forall i,j \tag{3}$$

where

F_v = the deterrence function for mode v,
C_{ijv} = the generalized costs for OD-pair i-j with mode v.

Finally, the number of trips by public transport can be calculated with the following equation:

$$T_{ijp} = T_{ij} \cdot \frac{F_p(C_{ijp})}{F_{ij}} = r \cdot o_i \cdot d_j \cdot F_p(C_{ijp}) \qquad \forall i,j \tag{4}$$

where

T_{ijp} = number of trips by public transport between nodes i and j,
F_p = the deterrence function for public transport,
C_{ijp} = the generalized costs for OD-pair i-j with public transport.

We will assume that a small change in the public transport system will only affect the number of trips by public transport, and will neither affect the total number of trips for an OD-pair (T_{ij}) nor the value of the deterrence function for all modes (F_{ij}). This assumption is acceptable for situations where 10–20 percent of all trips are made by public transport (e.g., in the Netherlands). The values of o_i and d_j are known, so by using equation (4) it is possible to calculate the number of trips. The values of o_i and d_j have to be determined for a situation which is comparable with the new situation. In case of an existing public transport system, these values can be calculated with an observed OD-matrix and for instance a weighted Poisson model (e.g., Hamerslag et al. [*20*]). When large changes are expected to occur, such as new residential areas, a traffic forecasting model should be used to calculate the values of o_i and d_j.

OBJECTIVE FUNCTION

Given is a set of possible routes Y with characteristics such as:

1. f_y = frequency of route y,
2. s_y = vehicle type used on route y (e.g. bus, tram),
3. N_y = set of nodes connected by route y,
4. T_y = in-vehicle times between the nodes of set N_y.

Only f_y will be used as the decision variable in the optimization process; all other characteristics are assumed to be fixed for each route. For instance, if a route can be used by two vehicle types, two identical routes have to be included each with a different vehicle type.

The set of possible routes Y can be generated in several ways, for instance with the method described by Ceder and Wilson (*21*), or such a set can be developed manually, using the interactive programs that will be included in the package. The final package will contain a model for the generation of routes.

The objective is to maximize the number of public transport passengers who can travel without transfers:

$$\max_{f_y} \sum_{1} \left\{ \sum_{J} [r \cdot o_i \cdot d_j \cdot F_P(C_{ijp})] \right\} \tag{5}$$

The generalized costs for an OD-pair are determined by the set of routes S_{ij} which offer a direct trip for the OD-pair *i-j*. Therefore:

$$F_p(C_{ijp}) = G(S_{ij}) \tag{6}$$

with S_{ij} = a set of routes with $i \in N_y$, $j \in N_y$ and $f_y \geq 0$ for $\forall \ y \in S_{ij}$, and $S_{ij} \in Y$.

When equation (6) is substituted in (5) the objective can be written as:

$$\max_{f_y} \sum_{1} \left\{ \sum_{J} [r \cdot o_i \cdot d_j \cdot G(S_{ij})] \right\} \tag{7}$$

The description of the public transport system results in a complicated analytical formulation of the objective. In order to derive a formulation which is more suitable for analytical analyses, a somewhat simplified description is used. For instance, let us assume an exponential function for F_p:

$$F_p = a \cdot \exp\left[-b \cdot (C_{ijp} + c)\right] \tag{8}$$

with *a*, *b*, and *c* as the coefficients.

The generalized costs can be written as:

$$C_{ijp} = g_{ij} + (60 \cdot h) / \left[\sum_{y \in S_{ij}} (f_y) \right] \tag{9}$$

with

g_{ij} = a constant for OD-pair *i-j*, determined by the time to access and to egress the system and the time spent in the vehicle,
h = a parameter for the calculation of the waiting time (including the weight of the waiting time).

Of course this description of the generalized costs is too simple in case there are several routes available for the OD-pair *i-j*, but it is sufficient to illustrate the problem. Equation (7) can then be written as:

$$\max_{f_y} \sum_{I} \left(\sum_{j} \left(r \cdot o_i \cdot d_j \cdot a \cdot \exp\left\{ -b \cdot \left[g_{ij} + \left[60 \cdot h / \left(\sum_{y \in S_{ij}} (f_y) \right) + c \right] \right] \right\} \right) \right) \tag{10}$$

CONSTRAINTS

The constraints of the problem are the available budget (*S1*) and the number of vehicles per vehicle type (*S2*). Furthermore, the possible frequencies are restricted to a limited set of integer values in order to make it easy for the passenger to memorize headways (*S3*), and of course only an integer number of vehicles can be assigned to a route (*S4*). These constraints can be written as:

$$S1{:}\quad \sum_{s} \left\{ k_s \cdot \left[\sum_{y} (nv_y \cdot b_y) \right] \right\} \leq K \tag{11}$$

with

K = the available budget,
nv_y = the number of vehicles that is necessary for route y,
b_y = a binary variable that indicates whether route y will be included in the summation ($b_y = 1$ if $s_y = s$; otherwise, $b_y = 0$),
k_s = a factor for the costs of using a vehicle of type s.

$$S2{:}\quad \sum_{y} (nv_y \cdot b_y) \leq mnv_s \qquad \forall\, s \tag{12}$$

with mnv_s = available number of vehicles of type s.

$$S3{:}\quad f_y \in f \qquad \forall\, y \tag{13}$$

with f = set of possible (integer) frequencies.

$$S4{:}\quad nv_y - 1 < (f_y \cdot nvf_y) \leq ny_y \qquad \forall\, y \tag{14}$$

with nvf_y = the number of vehicles that is necessary for the frequency of one vehicle per hour on route y.

SOLUTION METHOD

The formulated problem has a non-linear objective, linear constraints and a great number of integer variables. There are no efficient algorithms available to solve the problem without simplifying the formulation. For that reason Lampkin and Saalmans (*11*) and Dubois et al. (*12*) solve the problem in two stages: first, determine the routes and second, assign the frequencies. But, as there is a distinct relation between routes and frequencies, it would be better to determine them simultaneously. Therefore a new method has been developed. This method can be described as follows:

0. Set all frequencies equal to 0 and determine the elements of the sets S_{ij}.

1. Determine for each route y the efficiency r_y of an increase of the frequency by calculating the ratio of the number of extra passengers as a result of this increase and the necessary costs:

$$r_y = \frac{\sum_{m} \left\{ \sum_{n} [r \cdot o_m \cdot d_n \cdot G(S_{mn2})] \right\} - \sum_{m} \left\{ \sum_{n} [r \cdot o_m \cdot d_n \cdot G(S_{mn1})] \right\}}{k_{s_y} \cdot nvf_y \cdot (f_{y2} - f_{y1})} \tag{15}$$

with

$m,n \in N_y$,
$f_{y1}, f_{y2} \in f$, and $f_{y1} < f_{y2}$,

r_y = the efficiency of route y,
S_{mn1} = set of routes available for OD-pair m-n; $f_y = f_{y1}$,
S_{mn2} = set of routes available for OD-pair m-n; $f_y = f_{y2}$,
k_s = factor for the costs of using a vehicle of type s ($s = s_y$).

2. Select the route with the highest efficiency ratio and increase the frequency of that route.
3. Check the constraints *S1* and *S2* (eq. [11] and [12]); if they are no longer met the process stops; otherwise, continue with step 1.

A special feature of the method is the possibility of assigning some routes a fixed frequency, e.g., routes of other public transport companies, or routes of a vehicle type of which vehicles are no longer available. Because the optimization problem is limited to passengers who are being offered a direct trip, the values of the r_ys and the value of the objective function can quickly and easily be obtained. By restraining the set of possible routes Y, the method can also be applied to other design problems; for example, if we are only interested in the assignment of frequencies, the set Y consists of the existing routes.

ANALYSIS OF THE METHOD

Lagrange Multiplier

Although the method is heuristic, the efficiency of a route (r_y) can be regarded as an estimate of the Lagrange Multiplier, which is introduced when the first constraint is included in the objective and the integer constraints are dropped. The Lagrange formulation can then be written as:

$$\max_{f_y} \sum_{1} \left\{ \sum_{j} [r \cdot o_i \cdot d_j \cdot G(S_{ij})] \right\} - \mu \cdot \left\{ \sum_{s} \left[k_s \cdot \left(\sum_{y} (f_y \cdot nvf_y \cdot b_y) - K \right) \right] \right\} \qquad (16)$$

with μ = the Lagrange Multiplier.

An optimum will be found when the Kuhn-Tucker conditions are fulfilled. Therefore it is required that:

$$\frac{\delta \left\{ \sum_{m} \left[\sum_{n} (r \cdot o_m \cdot d_n \cdot G(S_{mn})) \right] \right\}}{\delta f_y} - \mu \cdot \frac{\delta \left\{ \sum_{s} \left[k_s \cdot \left(\sum_{y} (f_y \cdot nvf_y \cdot b_y) - K \right) \right] \right\}}{\delta f_y} = 0 \quad \forall y \qquad (17)$$

with $m,n \in N_y$.

$$\mu \cdot \left\{ \sum_{s} \left[k_s \cdot \left(\sum_{y} (f_y \cdot nvf_y \cdot b_y) - K \right) \right] \right\} = 0 \qquad (18)$$

$$\mu \geq 0 \qquad (19)$$

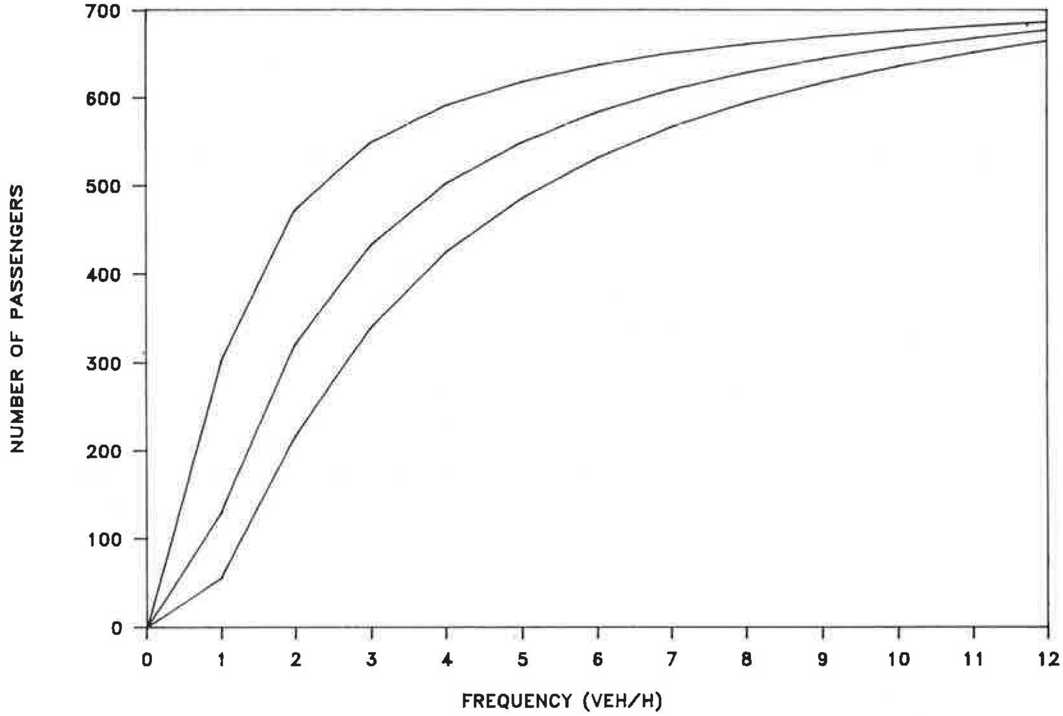

FIGURE 1 Possible relations between the number of passengers and the frequency offered.

Using equation (17) the Lagrange Multiplier μ can be written as:

$$\mu = \frac{\delta\left\{\sum_{m}\left[\sum_{n}(r \cdot o_m \cdot d_n \cdot G(S_{mn}))\right]\right\}}{k_s \cdot nvf_y \cdot \delta f_y} \quad \forall\, y \qquad (20)$$

If we take the limit of equation (15) as $(f_{y2} - f_{y1})$ approaches zero, the resemblance between the equations (15) and (20) is obvious. From this point of view the method is based on minimizing the variance between the values of r_y by increasing the frequency of the route with the largest r_y. The values of r_y will decrease gradually and finally converge to a solution in which they are more or less equal to each other and consequently equal μ.

Concavity

If the objective function is concave over the decision variables (f_y), the Kuhn-Tucker conditions are sufficient to determine the optimum. For an exponential, as well as for a lognormal deterrence function it can be shown that the objective is concave for frequencies greater than a certain value, depending on the coefficient being used (see Figure 1). The concavity of the objective function also guarantees that an increase of f_y will result in a decrease of r_y, and consequently that the method converges to a solution.

Quality of the Solution

As the method can be used for several design problems, there are two aspects that have to be analyzed:

1. The assignment of frequencies,
2. The selection of routes.

Both aspects have been analyzed with the use of the simplified objective described with equation (10). When we restrict the problem to assigning frequencies only, we can derive an alternative solution technique. By introducing the first constraint (11) in the objective (10) the Lagrange equation is derived. In the optimum situation the Kuhn-Tucker conditions should be fulfilled. These conditions result in a set of non-linear equations, which because of the concavity of the objective can be solved using Newton-Raphson (see Simmons [22]). For these analyses a simple network (Figure 2 and Table 1) has been used.

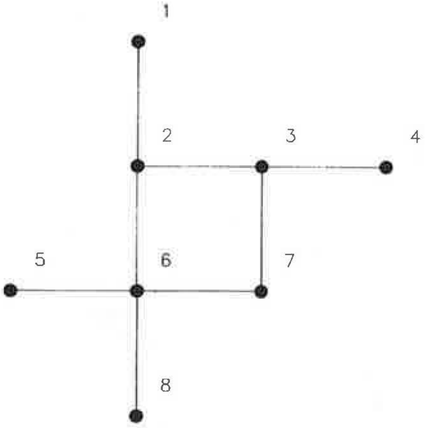

FIGURE 2 Network for analysis of the method.

For several sets of routes the frequencies were determined using Newton-Raphson as well as the new method with $f_{y2} - f_{y1} = 0.1$ and with $f_{y2} - f_{y1} = 1$. The results show that with a small stepsize the new method gives the same results as Newton-Raphson. If we use the integer stepsize, the results are quite satisfactory. The results are shown in Table 2.

The selection of routes is more difficult to analyze as the method used to analyze the assignment of frequencies cannot be used for the selection of routes. Therefore this has been done by comparing the first four selected routes with the results of every possible combination of four routes from the set Y. For each combination the Newton-Raphson method was used to determine the frequencies and the value of the objective. This comparison showed that the selected four routes were the best combination. Moreover, this analysis showed

TABLE 1 VALUES OF o_i AND d_j

Zone	o_i	d_j
1	2	4
2	10	10
3	2	2
4	2	2
5	4	2
6	10	10
7	4	4
8	2	4

TABLE 2 COMPARISON OF CALCULATED FREQUENCIES FOR A TEST NETWORK

	Frequency		
Route	Newton-Raphson	$(f_{y2} - f_{y1}) = 0.1$	$(f_{y2} - f_{y1}) = 1.0$
1-2-6-5	1.9	1.9	2.0
1-2-6-7	2.3	2.3	2.0
4-3-7-6-5	1.4	1.4	1.0
4-3-2-6-8	2.4	2.4	3.0
No. of direct trips	696.5	696.2	692.9

that 3 percent of the combinations were near-optimal, i.e., within 2 percent difference from the optimum solution. Analyses with a more realistic network gave similar results.

ADDITIONAL FEATURES

Although the test showed good results for the method, there are indications that the purely additive nature of the method might have a negative effect on the optimal quality of the selected network. Therefore, an exchange routine to check the solution has been introduced. This routine is based on the interpretation of the efficiency r_y as an estimate of the Lagrange Multiplier μ and checks whether the solution can be improved by replacing a selected route with another. If an optimum solution has been found it will not be possible to improve the solution in this way because the efficiency of the routes will be more or less equal. Moreover, an interactive routine is developed which can be used to analyze a solution by fixing frequencies, dropping routes or introducing extra routes, and to restart the optimization process, for example, to assign frequencies or to select alternative routes given the adapted solution. Therefore, the model does not present the solution, but allows the planner to play around with an optimized solution. Besides, the possibility of using different starting sets *Y*, developed manually or with the use of a route generation model, also offers different solutions from which the planner may choose.

INCORPORATION OF THE PUBLIC TRANSPORT SYSTEM IN THE MODEL

Another aspect which determines the quality of the model is the description of the public transport system. Some special features of this description will be discussed in this paragraph.

The area that is the subject of the study is divided into zones, which are located around the stops. For each zone an access- and egress-time is determined. Trips from or to the study area are supposed to enter or leave at fictional zones located at the major transfer points between the local and regional public transport system.

The generalized costs consist of the weighted sum of the time-elements of a trip by public transport, namely the access- and egress-time, the in-vehicle time and the waiting time. The in-vehicle time is weighted with a coefficient which depends on the vehicle type. The waiting time can be calculated with several formulas, so it is possible to account for the expected regularity of the route, for example.

A special situation occurs when several routes offer a direct trip for an OD-pair. In some models the frequencies of the routes are added, but this is clearly a very optimistic approach. We will use an approach similar to that of Lampkin and Saalmans (*11*), but instead of calculating an average waiting time we also take amount of the possibility of bunched arrivals of vehicles. In this approach it is assumed that a passenger uses the first vehicle that arrives at the stop. This assumption has often been criticized (e.g., Marguier and Ceder [*23*]), but this criticism is not supported by empirical evidence.

All kinds of routes can be used in the set of possible routes: one-way and two-way routes, routes with loops, express routes and so on. Moreover, it is possible to use different deterrence functions to account for the different behavior of separate groups of travelers.

EXAMPLES

The model which has been described is suitable for a personal computer (Olivetti M24, MS-DOS, 640KB) and can be used for a network consisting of 250 nodes with a maximum of 150 zones, and a maximum of 750 possible routes.

Fictional Network

As an example of the design process using the optimization model the network of Figure 3 is used. A set of possible routes *Y* was generated manually, and consists of 75 routes. Two alternative demand patterns are considered: a midday period and an evening peak hour. For the midday period a network is designed which offers 1205 passengers a direct trip, given a fleet size of 10 vehicles. This solution cannot be improved using the exchange routine. For the evening peak hour two networks were developed: a complete new network and a network which uses the midday network as a base network. A comparison of these two networks shows that adding new constraints, such as the use of a base network, results in less

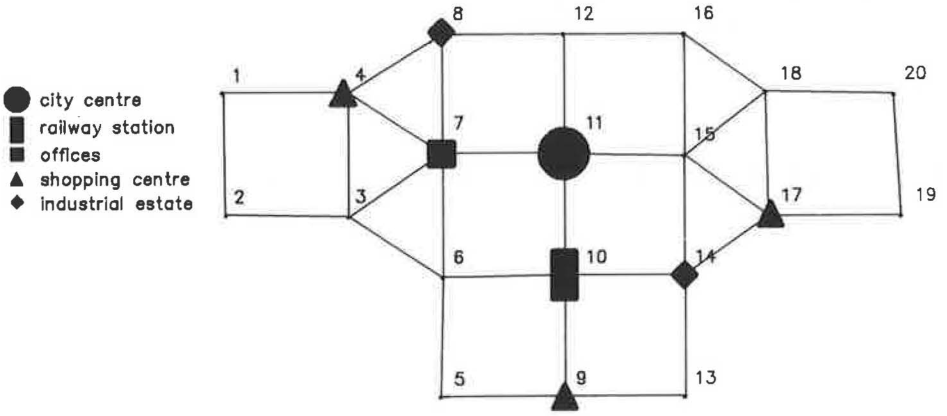

FIGURE 3 Test network.

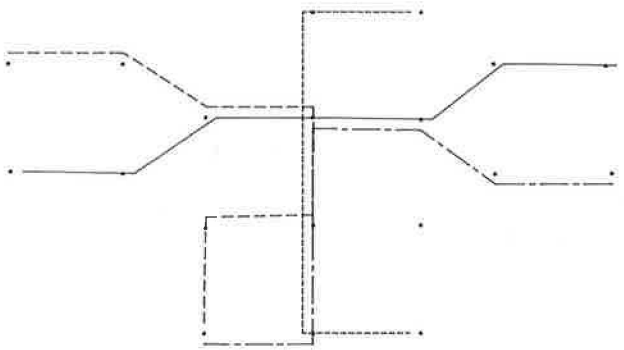

FIGURE 4 Selected network with four routes (midday).

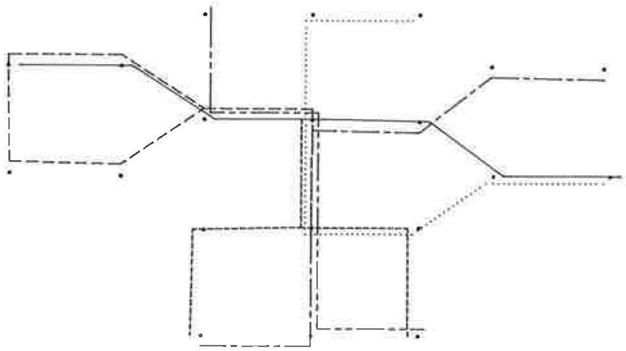

FIGURE 5 Selected network with six routes (peak).

optimal solutions. On the other hand, using a base network has the advantage that the network remains recognizable for the passenger. The major point, however, is that the optimization model can be used for both strategies. Results of the tests are shown in Figures 4, 5 and 6, and in Table 3.

Existing Network

The optimization model is also tested with data from the city of Groningen in the Netherlands (170,000 inhabitants). This network consists of 182 nodes and 115 zones (Figure 7). Three different starting sets Y were used. The first set consists of the current routes run by the local public transport company. The second set was constructed by splitting the existing routes at the city center and connecting them in all possible ways. The third set was derived with the use of basic design principles. The shortest routes from the city center and the railway station to 14 termini were determined and these route-segments were combined in such a way that each route passes the railway station and the city center. The optimization model was used to determine the best possible network based on the possibilities contained in sets 2 and 3, given the demand pattern for the morning peak hour. The first set, the existing routes, is used for comparison.

The results of these tests can be found in Table 4. They clearly indicate that the optimization method is suited for realistic situations. Sets 2 and 3 yield similar results for the number of direct trips, an increase of 300 trips. Set 3, however, is clearly the best solution when the total number of trips is included. This is due to the basic design principles used to construct set 3, because of which a network can be developed offering good transfer facilities.

These analyses show that the set Y is an additional constraint; set 2, which is determined by the network, yields a lower result compared to set 3, which is developed with fewer constraints. It is up to the planner to decide which constraints will have to be included in the set of possible routes. It should be noted that during these tests the number of routes was not used as a constraint. The method itself stopped selecting routes at 9, respectively 7 routes.

CONCLUSIONS

We have presented a new optimization model for the design of public transport networks. Special features of the optimization method are as follows:

1. The simultaneous selection of routes, assignment of frequencies and the determination of the number of passengers,
2. The single optimization process which can be used for several design problems, ranging from short-term analyses to long-term decisions,
3. The application on a personal computer, which together with the interactive approach and the inclusion in a software

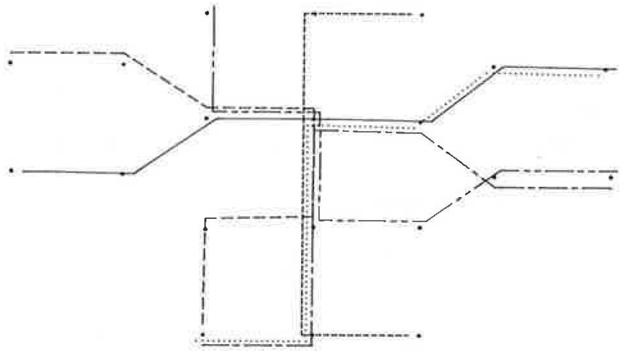

FIGURE 6 Selected network with six routes using a base network (peak).

TABLE 3 CHARACTERISTICS OF THE RESULTS WITH THE TEST NETWORK

Period of Day	Base Network	Direct Trips	No. of Vehicles	No. of Routes
Mid-day	No	1,205	10	4
Peak	Yes	1,529	15	6
Peak	No	1,543	15	6

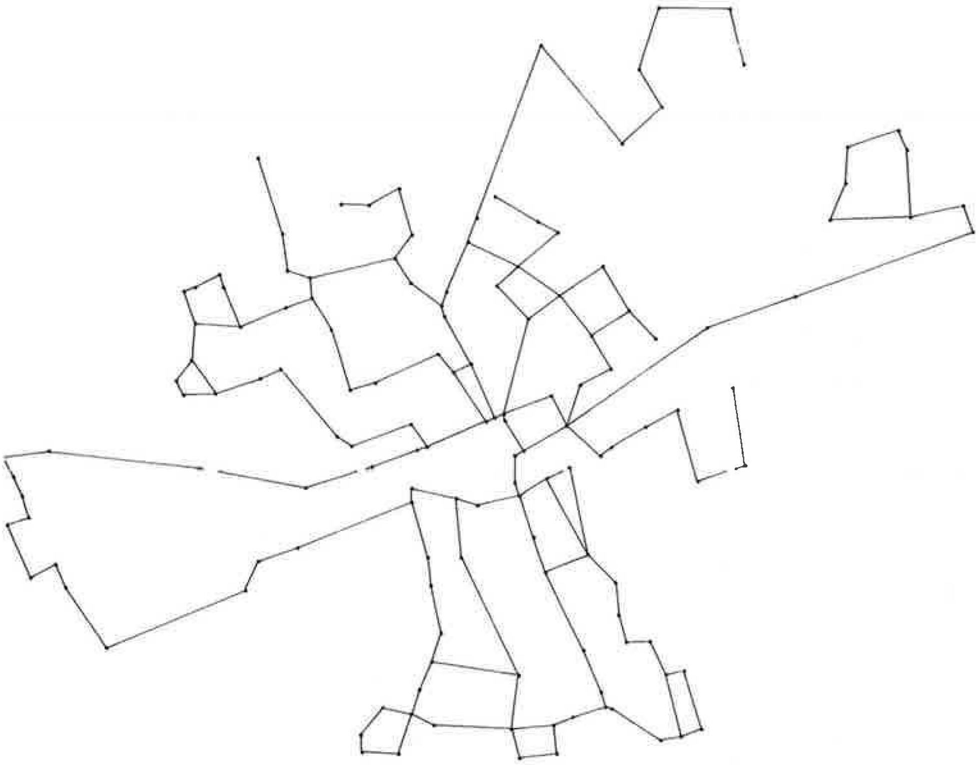

FIGURE 7 Network of Groningen.

TABLE 4 CHARACTERISTICS OF THE RESULTS WITH THE NETWORK OF GRONINGEN

Set	Direct Trips	Total Trips	No. of Vehicles	No. of Routes
1	3,494	5,242	55	10
2	3,818	5,393	56	9
3	3,805	5,746	55	7

package, enables the use of the model by the planner independently,

4. The possibility of taking into account all kinds of additional constraints, such as a base network, existing routes, a maximum number of routes, etc.

The method has proved to give good results with test networks and with actual data. Further research will be carried out to develop a model to generate a proper set of possible routes which can be used as input for the optimization model.

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Abridgment

Bus Transit Subsidies in Connecticut

HERBERT S. LEVINSON

This paper traces the development of state transit operating subsidies in Connecticut and analyzes various operating subsidy options. From these analysis, an efficiency incentive formula was recommended to the Connecticut Public Transportation Commission in 1985. Under this formula, the state's share of operating costs increased as the farebox recovery ratio increased. Because this approach would increase state aid to some independent transit districts and reduce it to others, it was not acceptable to the state legislature. A revised "constant state share" formula, in which the state pays the operating deficit up to 67 percent of the total operating costs subsequently was implemented by the state Department of Transportation and legislature.

This paper traces the development of state transit operating subsidies in Connecticut. It analyzes the growth in subsidies and sets forth ways to better allocate state operating assistance. It identifies the 1987 subsidy policy that was adopted by the state Department of Transportation (DOT) as the outgrowth of a 1985 study of bus subsidy options (*1*).

BACKGROUND

Public financial assistance to urban transit has become a problem of national scope. No longer able to cover operating costs from farebox revenues, transit now relies on growing operating subsidies from local, state, and federal governments. Local and state contributions will assume even greater importance as federal operating assistance declines.

State and local involvement in Connecticut's transit systems mirrored the national trends. Service types and systems grew in direct response to the operating environment in the 1970s. Three key underlying factors were the threat to discontinue service; gasoline shortages, costs, and conservation needs; and federal funding policies (*2*).

The state's policy of providing operating subsidies to public transport began in the late 1960s. The New Haven Commuter Rail Line was sustained from 1960 to 1970 as studies were made on how best to provide the rail service. Full subsidies began June 1, 1971, in equal partnership with the Metropolitan Transportation Authority (MTA) of the State of New York. This was accompanied by programs to provide new rolling stock, build a new maintenance facility, compensate for deferred maintenance, modernize the signal system, and convert to commercial 60-cycle power.

Operating subsidies to urban bus systems grew out of the potential discontinuance of Connecticut Company service in Hartford, New Haven, and Stamford. (The Connecticut Company had been affiliated with the New Haven Railroad.) A 120-day strike in November 1972 in the three areas led to resumption of service on March 26, 1973, with a two-year state guarantee of operating deficits. The state required that transit districts be formed within two years. Threatened again with service discontinuance, the state purchased the assets of the Connecticut Company on May 26, 1976, using Federal Section 3 funds to cover 80 percent of the capital cost it established. Connecticut Transit was established to provide bus service in the three cities.

The decision to establish Connecticut Transit statewide reflected both the need for the state to act quickly, and the apparent inability or unwillingness of the major cities to act (including some perceptions of extensive urban-to-rural subsidies in other sectors of the economy).

Connecticut Railway and Light (CR&L) also struck in November 1972, but it was allowed to fail. The profitable routes were picked up by four companies, which continued service until purchased by the Greater Bridgeport Transit District in 1979-1980. Service was provided by the Northeast Transportation Company in Waterbury, and by Dattco Incorporated and New Britain Transportation Company in New Britain. Service in Norwalk, New London, Meriden, and Wallingford continued to operate at a minimum level, with the State arranging subsidies to assure its continuance.

Spurred by federal initiatives, "independent" transit districts were formed throughout the state. Federal demonstration projects provided funding for the start-up of transit systems in the Valley and Westport Transit Districts. Since the availability of Section 5 Federal operating assistance funding in November 1974, the Norwalk, Middletown, and Milford Transit Districts have been formed, and bus service has been expanded. The Southeast Transit District (SEAT), formed in Danbury by merging two local transit districts, offered a major expansion of service. The Housatonic Area Regional Transit District (HART) became active in July 1982 in the Danbury area.

Within the Connecticut Transit service areas, the state has covered all operating deficits. It constantly monitors the bus service to assure a reasonable balance in costs and revenues.

When transit districts began to improve and expand service in 1974, the communities wanted a greater level than that provided in areas fully supported by the state. To assist and guide transit districts, Connecticut DOT developed a "funding formula." Using this formula as a guide, state operating agreements were negotiated by ConnDOT with each transit district.

1. The state's formula, derived for a 60 percent farebox cost recovery ratio, was keyed to the farebox recovery ratios obtained in the three Connecticut Transit cities—Hartford, New Haven, and Stamford. When the revenues exceeded 60 percent of the expenses, the state paid the entire deficit. If

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40 Hemlock Road, New Haven, Conn. 06515.

less than 60 percent of the expenses were covered by the fares, the state paid the first 40 percent and then shared the remaining deficit equally. Each district was required to pay 50 cents for each dollar it spent below the 60 percent threshold. The state then matched it under a "distribution of income concept" to avoid a further property tax burden for municipalities within the transit district.

2. By about 1983, the farebox recovery ratios on the three Connecticut Transit systems ranged from 45 to 50 percent. Accordingly, the required recovery ratio for other systems was reduced to 40 percent by the state legislature (Public Act 8319, and Connecticut General Statutes Section 7-273M). However, when a transit district recovered less than 40 percent, the remaining deficit was shared between the transit district and state by the first formula.

3. The revised formula produced a sharp discontinuity in the state's contribution when the farebox recovery ratio fell below 40 percent. It was most pronounced whenever a transit district fell just short of the specified threshold. This unduly penalized municipalities when their cost recovery ratios ranged from 30 to 40 percent. For example, if a transit district recovered 40 percent of its costs from the farebox, the state would cover 60 percent. But if it covered 38 percent, the state would cover 51 percent, leaving 9 percent to be covered by the District from other sources. But when the cost recovery ratio was less than 20 percent, the state actually would pay more than 60 percent of the operating cost.

4. The state subsidy policy has two other weaknesses: it does not differentiate between small and large systems, and it lacks a strong incentive for productivity or efficiency.

OPERATING EXPERIENCE

Bus transit services, management methods, and subsidy arrangements reflect Connecticut's history and geography. The multinucleated character of the state's urban development; the many political jurisdictions (especially in Fairfield County); the past failures of the Connecticut Company and CR&L services, and the varied responses to improving transit services have produced a patchwork of service patterns, management methods, and funding arrangements. Disparities in system size, operating territory, and community responsiveness have led to wide variations in performance, productivity, and operating ratios.

Operating Performance

In 1984, 17 systems, with a fleet of 652 buses, carried 36.8 million passengers. Revenues of $24.5 million and operating costs totaling $50.9 million resulted in a deficit of $26.6 million, and an aggregate farebox recovery ratio of 48 percent. Approximately $25.4 million of the deficit came from the state and $0.8 million from local areas.

Operating patterns and performance varied by city size and by service provider. The three Connecticut Transit systems (Hartford, New Haven, Stamford) accounted for 65 percent of the fleet, 74 percent of the revenue, 70 percent of the expense, and 65 percent of the deficit; their aggregate operating ratio was 51 percent. The five state-managed, privately operated systems accounted for 7 percent of the passengers and 8 percent of the deficit; their aggregate operating ratio was 45 percent. The Greater Bridgeport Transit District accounted for 11 percent of the passengers and 10 percent of the deficit; its operating ratio was 48 percent. The seven other transit districts accounted for 9 percent of the passengers and 17 percent of the deficit. Their aggregate operating ratio of 33 percent resulted in a collective local subsidy of $803,000.

Subsidy Patterns

The state covered all operating deficits for state-owned or state-run systems, and covered operating costs for the independent transit districts based upon the revised 60-40 formula. The total 1984 subsidy per passenger averaged 71 cents, of which 2 cents came from the local community and 69 cents from the state (or federal government). The non-local subsidies per passenger ranged from less than 60 cents in Hartford and New Britain to more than $2.50 per passenger in Wallingford and Westport. Independent transit districts generally received more non-local support per passenger than the Connecticut Transit or ConnDOT-managed operations. The state's share of operating costs ranged from 45 percent in Hartford to 60 percent in Westport and 75 percent or more in Bristol, Meriden and Wallingford.

SUBSIDY PRACTICES IN OTHER STATES

State operating assistance programs reflect specific traditions, political arrangements, urbanization patterns, and economic circumstances. Maryland provides a high level of support: Texas provides none. Ohio and Washington allow localities to choose which taxes can be used to support transit; however, assistance to large metropolitan areas such as New York City is negotiated. Farebox recovery ratios are mandated in California, Illinois, Maryland, and Pennsylvania, and serve as guides in Connecticut and Ontario. Cost recovery percentages range from 20 percent in California to 50 percent or more in Maryland, Illinois, and Ontario. These targets or requirements are implemented to encourage improved operating/financial efficiency and to limit reliance on state subsidy. The states of Illinois, Minnesota, Ontario, and Pennsylvania vary their cost recovery requirements according to urban area populations or bus fleet size, with somewhat lower requirements for smaller urban areas. However, Ontario and Pennsylvania require local contributions even when communities meet specified revenue/cost ratios. The Minnesota program is unique in that it explicitly specifies fixed local shares.

Connecticut's communities participate in a highly satisfactory arrangement with the state in terms of operating assistance. Connecticut ranks high compared to other state programs in terms of the state subsidy per passenger, and the proportion of operating costs covered by the state; but its subsidy arrangements (as of mid-1985) could be improved by reflecting city size and by modifying state support to promote operating efficiency.

There also is an important administrative/philosophical difference between Connecticut and other states. Most other states (i.e., California, Pennsylvania) view transit mainly as a *local* responsibility; systems are locally controlled, and the local transit agencies contribute to the operating deficits. A few states, Rhode Island and New Jersey, own and operate mutually all urban transit, because of their small size, and the nature of their local markets. Connecticut, in contrast, owns and operates major systems, and sets policy for the others; state, rather than local control predominates; and local financial responsibility is minimized. Maryland is the only other state which operates a major transit system (Baltimore MTA), and simultaneously sets subsidy policy for the small bus systems.

OPERATING SUBSIDY OPTIONS

Various short-range bus operating subsidy options were based on the following assumptions:

1. The ownership, management and operations of the state's bus systems would remain unchanged in the short run.
2. Local subsidy would be required only where there is an independent transit district, and its cost recovery falls below a specified threshold.
3. Threshold criteria would be keyed to the 40 percent cost recovery target specified by Public Law 83-19. (If this target changes, there would be a corresponding change in each option.)
4. Subsidies would be allocated on a systematic basis.
5. The total state subsidy would remain at 1984 levels for analysis purposes.

Some 13 specific subsidy options were analyzed in terms of factors such as acceptability, efficiency, equity, and predictability. They varied in three ways: use of a single criterion versus setting criteria by service area population; use of mandated versus target operating ratios; and mechanism for relating state subsidies to the farebox ratio—i.e., use of an efficiency-incentive versus a fixed local share, or a shared deficit. They included the status quo as well as options that provided equal state subsidies per passenger.

RECOMMENDED SUBSIDY POLICY

The analyses of alternate subsidy policies practices in other states led to the following recommendations:

1. Bus operating subsidies should be systematically allocated to enhance the objectivity and credibility of the state's subsidy allocation procedures. The subsidy formula should (a) differentiate between larger and smaller transit systems, and (b) provide financial incentives for improved operating efficiency. The local subsidy as a percentage of operating cost should increase as the farebox recovery ratio declines.
2. The recommended formulas were as follows:
    (a) For urban areas of 100,000 or more population, the state would pay up to 60 percent of the operating cost when the farebox recovery ratio is 40 percent or more. When the farebox recovery ratio is less than 40 percent, the state subsidy payment as a percent of operating costs would be 30 + .75 [100 × cost recovery ratio].
    (b) For urban areas of less than 100,000 population, the state would pay up to 64 percent of the deficit when the farebox recovery ratio is 36 percent or more. When the ratio is less than 40 percent, the state subsidy payment as a percent of operating costs would be 37 + .75 [100 × cost recovery ratio].

These formulas were keyed to a 40 percent cost recovery criterion for Connecticut transit. If this criterion changes, the formulas should be adjusted accordingly.

3. The fixed local share represents a practicable alternate approach, since it is probably the most attractive from the perspective of the individual transit districts.

IMPLEMENTATION

The efficiency incentive formulas were adopted by the Connecticut Public Transportation Commission in 1986, and submitted to the State General Assembly and ConnDOT for their approval. Discussions ensued for 18 months regarding the advisability of implementing the formulas. The formulas were not perceived as politically acceptable, as some communities would have to pay more local subsidy. During the protracted discussion period, two events took place that required changes in the formula: (1) The farebox recovery ratio declined in all systems throughout the state, requiring a change in the basic criteria. Under the initial proposals, all systems would get less state support than they did under the state formula then existing. (2) The state amassed a large revenue surplus.

Accordingly, a modified "constant state share" formula was proposed by the CPTC to ConnDOT and the state legislature. Under this formula, the Connecticut Department of Transportation will pay 67 percent of the approved operating expenses of transit districts or the entire deficit, whichever is less. It requires that transit districts receive 33 percent of their expenses through the farebox or make up the difference through local sources. No transit district would receive reduced funding under this plan. The plan approved by ConnDOT and the state legislature in June 1987 will provide an additional $500,000 annually to the seven independent transit districts.

IMPLICATIONS AND EXTENSION

The following implications emerge from the analysis of bus operating subsidies in Connecticut: first, farebox cost recovery ratios can be used to apportion state operating assistance. Second, the allocation formula concept should provide an incentive to efficiency. The state should cover a higher proportionate share of operating costs as the local system approaches (or meets) specified targets. However, in implementing such a formula, care must be taken to assure that individual systems are not unduly penalized when the formula is used. Thus, applying the formula would be more appropriate when a state begins an operating subsidy program, rather than when it changes a program already established. Third, a "constant-state share" of operating deficit provides a practical alternative—one which can also encourage maximum local efficiency.

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Estimating Unmet Travel Needs Using Secondary Data Sources

MICHAEL G. MCNALLY, WILFRED W. RECKER, AND ROGER F. TEAL

This paper presents a set of procedures for estimating transit needs using readily available data sources, applies these procedures to a specific study area, and generates a spatial distribution of transit needs. This distribution of need is used as input to the design of a local transit service for the study area. Ridership data from the implemented transit service is then used to check the reasonableness of the transit need distribution that was generated from the estimation procedures. The results indicate that secondary data sources can be used to develop reasonable estimates of transit needs and to identify specific areas that have high unmet needs; these need estimates can be used to design actual services that are responsive to the travel desires of local residents.

In theory, the design of a public transportation service should be primarily responsive to the needs of the population that will utilize it. In practice, this principle is often more honored in the breach than the observance. Transit service design may reflect historical factors, personal preferences of agency planners or elected officials, or simply conventional wisdom, rather than being the best means of meeting the needs of the transit-using public. One major reason that service design often is not well matched to user needs is the difficulty of determining precisely what those needs are.

Determining unmet travel needs is difficult because it involves several stages, and at each stage considerable data are seemingly required. First, the criteria that establish need must be determined; then these criteria must be applied to the service area population. Second, those with unmet needs must be identified and located in space. Third, the desired destinations of those with unmet needs must be determined. Finally, it is necessary to assess how much of the estimated need may potentially be satisfied by existing transit services. What then remains are the travel needs that attempts are made to meet through new or redesigned services.

This paper presents a set of procedures for estimating transit needs using readily available data sources, applies these procedures to a specific study area, and generates a spatial distribution of transit needs. This distribution of need is used as input to the design of a local transit service for the study area. Ridership data from the implemented transit service are then used to check the reasonableness of the transit need distribution that was generated from the estimation procedures. The results indicate that secondary data sources can be used to develop reasonable estimates of transit needs and to identify specific areas that have high unmet needs; these needs estimates can be used to design actual services that are responsive to the travel desires of local residents.

A METHODOLOGY FOR ESTIMATING SPATIALLY DISTRIBUTED UNMET TRAVEL NEEDS

An estimation of unmet travel needs can be accomplished on two separate levels:

- a measure of unmet needs based on a comparison of travel behavior under varying levels of mobility and
- a measure of unmet needs relative to current transit service.

Each of these measures is, to some extent, dependent on the trip-making behavior that can be expected from residents of a particular study area. As a preliminary to the analysis of unmet needs, an estimate of the total number of trips currently being generated by study area residents must be made. This is accomplished using a segmentation approach based on characteristics that are accepted as being the primary determinants of trip generation.

In the segmentation approach, households are first disaggregated based on type of dwelling unit (single, multiple) and vehicle ownership (0, 1, 2, or more). Based on this stratification, person trip rates are then obtained for various trip types (home-work, home-shopping, etc.). The trip generation tables are then restratified by income level (high, medium, and low), and a final set of trip generation rates are produced. Using census data to classify the households within the study area, these trip rates are then applied to each group of stratified households in each census block. The result is a spatially disaggregated estimate of trip making within the study area. The geographical distribution of estimates of home-based work and nonwork trips forms the basis for the assessment of unmet travel needs.

These procedures are not intended to be used as a means of forecasting ridership levels, but rather as a tool for locating the areas with highest transit need, both in absolute terms and relative to existing transit services. By developing a spatial disaggregation of estimated unmet needs, it should prove possible to design transit services that will make the greatest possible contribution to mobility. These procedures produce information that permits more rational choices to be made about the type of transit that is most appropriate for an area and the specific configuration (in terms of routing, access points, etc.) of the transit mode utilized.

Institute of Transportation Studies and Department of Civil Engineering, University of California, Irvine, Irvine, Calif. 92717.

Measure of Unmet Needs Relative to General Mobility Considerations

A mechanism for uncovering unmet travel needs/desires involves assessing the trip-making behavior of residents as a function of the mobility available to them. It is generally acknowledged that access to the private automobile provides the greatest degree of mobility to urban residents. Thus, households with greater numbers of automobiles tend to travel more; those with a surplus of automobiles ostensibly travel to a degree limited not by mobility but rather by constraints associated with time and money. This principle enables the estimation of unmet travel needs/desires for households relative to comparable (in the socioeconomic sense) households with "ideal" mobility.

This estimation is accomplished for the study area using the segmentation approach already discussed, with households segmented into homogeneous groups relative to income status, type of dwelling unit, and number of automobiles. Trip rates for both work and nonwork trips are then applied to each group to estimate the numbers of trips generated. The variation of these trip rates over the number of automobiles available to the household, in any particular segment with like household structure and income category, is then an estimate of trip needs/desires not met because of mobility limitations.

Two separate measures of unmet needs are estimated:

1. level 1—based on projected trip-making behavior if transit services equivalent to mobility afforded one-automobile households were provided and
2. level 2—based on projected trip-making behavior if transit services equivalent to mobility afforded households with two or more automobiles were provided.

The latter measure represents an estimate of the trips that would be made by residents if mobility restrictions were virtually nonexistent while all other factors remained unchanged (e.g., household income and residence location). The increment of trips that would be generated with removal of mobility constraints over that currently generated thus represents a measure of the trip deficit faced by residents of the study area.

Measure of Unmet Needs Relative to Current Transit Service

A rather different approach is needed to determine unmet travel needs relative to existing transit service. The spatially disaggregated trip deficits obtained by the previous procedure must be transformed into desired trip patterns (at least in terms of direction of travel); then the correspondence between these desire lines and existing transit service must be determined. An estimate of directional travel is developed by using the average daily traffic (ADT) volume measures for the principal roadways within the study area as indicators of desired travel tendencies.

Average volumes along the principal north-south (N-S) and east-west (E-W) roadways in the study area are summed and used to compute probabilities of trips in each of the four compass directions. Thus, if Census Block 100 generated 1,000 home-based trips per day, and 30 percent of the travel in the study area is in a northerly direction, then 300 trips per day from this census block are assumed to flow northward.

The second part of the procedure involves estimating the portion of the identified trip deficits that could potentially be served by existing transit services without transfer. Based on accepted principles, it is assumed that transit routes are not readily accessible to households that are located at distances greater than 0.25 mile from the nearest bus route. Thus bands are drawn around transit routes, and only those within the band are considered potential transit users. For all households with transit access, the trip deficits are then distributed in each of the four principal directions, based on the probabilities calculated from the ADT volumes. The number of such desired trips that could possibly be accommodated by any of the existing transit routes without need for transfer is then estimated based on the simple criterion of whether a transit route serving the desired destination is accessible. This produces an extremely liberal estimate of need fulfillment, as many trips by households with home end access to transit will be unable to utilize transit because of its inability to access a desired destination. If more detailed information on destinations is available, it can be used to adjust the potential need fulfillment downward.

DESCRIPTION OF THE STUDY AREA

The methodology described previously was applied as part of a study to determine any unmet transit needs of residents of a small urban community in Southern California. Bell Gardens, California, is an inner suburb of Los Angeles. Located approximately 10 miles from the Los Angeles central business district (CBD), the city encompasses only 2.4 square miles but has a population of approximately 35,000 residents (1980). Despite the high population density of more than 14,000 persons per square mile, the city's housing stock is predominantly composed of detached units; nearly 60 percent of all households reside in single-family units.

In 1981, Los Angeles County voters passed a one-half-cent sales tax increase dedicated to mass transportation; 25 percent of this increase is returned to local cities as a function of population for discretionary use in local public transit projects. Cities such as Bell Gardens have a range of needs that could be addressed by a variety of transit alternatives. Although several specific needs were analyzed as part of a larger project, the focus of this paper is a general-population transit service targeted to improve mobility within the city and to neighboring activity centers.

Figure 1 depicts the relative location of Bell Gardens and various regional activity centers. North-south regional access is provided by Interstate 710, immediately adjacent to the western city limit. East-west flows are partially serviced by Interstate 5, just north of the city, and by a major artery running due east-west across the region through the heart of the city.

Bell Gardens should be expected to have high transit needs, for it is one of the poorest communities in Southern California. The median household income is one-third less than the average for California, and 23 percent of the families have incomes below the poverty level. In fact, 60 percent of all households are considered low income by regional standards. In addition, 15.2 percent of all its households do not own an

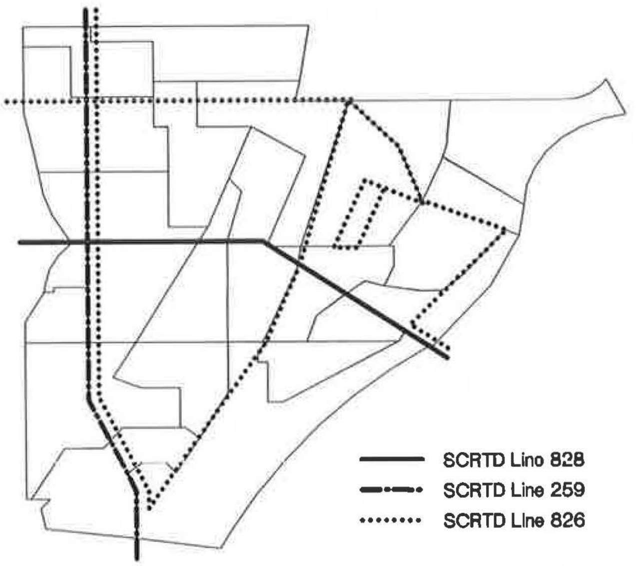

FIGURE 1 Current fixed-route transit service.

automobile, compared to 10.1 percent for California as a whole and 12.7 percent for Los Angeles County. The city also contains a high concentration of youths; 42 percent of the residents are younger than 18 years of age. Although the elderly population is relatively small (only 5.6 percent), more than 30 percent of this group stated that they had a disability that made using conventional fixed-route transit difficult or impossible. This is twice the California average.

Table 1 summarizes salient sociodemographic characteristics of Bell Gardens and also provides similar information for several neighboring cities, Los Angeles County, and the State of California. Overall, the characteristics of Bell Gardens' population are definitely oriented toward high transit needs. Despite this, however, Bell Gardens residents made less than average use of transit for work trips.

Transit service in Bell Gardens at the time of this study consisted of three bus routes operated by the Southern California Rapid Transit District (SCRTD) (Figure 1). SCRTD Route 828 provides service through the city along a major east-west corridor, with transfers to most major SCRTD north-south routes (including routes serving the Los Angeles CBD). SCRTD Route 258/259 provides north-south service with transfers to major east-west routes into downtown Los Angeles and the San Gabriel Valley. Finally, SCRTD Route 826 provides a predominantly local service to neighboring communities in a rather comprehensive, if somewhat tangled, routing scheme. This route provides service to nearby, major commercial activity centers and hospitals and passes within a quarter mile of virtually all residents of Bell Gardens.

Headways for the local service, Route 826, average 30 minutes in the peak periods, 45 minutes off peak, and 60 minutes on weekends. Service is provided from approximately 6:00 a.m. to between 7:00 and 10:00 p.m., depending on the day and bus stop location on the route. Both regional routes, Route 259 and Route 828, provide equivalent service weekdays and weekends, with headways of 40 minutes and 60 minutes, respectively, constant over the full service period (approximately 6:30 a.m. to 7:00 p.m. for both routes).

APPLYING THE METHODOLOGY TO THE STUDY AREA

Data and Procedures

The socioeconomic data used in the study were derived principally from the 1980 census. To facilitate the analysis of the possible variation of transit needs within the city, data were disaggregated to a level of 22 census block groups that comprise the city.

A limited range of sociodemographic factors was purposefully chosen both to streamline analysis and interpretation and to make use of available regional databases (e.g., trip generation rates). Clearly, a range of alternative classification variables is available—in particular, household role and lifestyle factors that in several studies have been shown to be significant determinants of variation in travel behavior Unfortunately, the effort required to conduct such analyses precludes the inclusion of such variables in a simplified estimation procedure. Furthermore, variations across lifestyle variables typically lead to indeterminant classifications of individuals and households. What is important, however, is to determine if the lifestyles of the study area's population are not so dissimilar from those of the surrounding area as to introduce potential errors by using regional trip rates.

In addition to census data, several regional databases were used to develop the estimates of unmet transit needs for Bell Gardens. The original Los Angeles Regional Transportation Study (LARTS) Transportation Model, which was based on the 1967 origin-destination study, incorporated a two-dimensional stratification based on type of dwelling unit and vehicle ownership (0, 1, 2, or more) to forecast daily person trip rates for five trip types (1, home-other; 2, other-other; 3, other-work; 4, home-work; and 5, home-shopping). An update of the original origin-destination study was conducted by the Southern California Association of Governments (SCAG) and the California Department of Transportation (CALTRANS) in the *1976 Urban and Rural Travel Survey* (*1*). Based on these 1976 data, the Santa Ana Transportation Corridor study (*2*) updated the LARTS trip generation rates and restratified the trip generation tables to include an income stratification (low, middle, high) in addition to the original stratifications based on housing unit type and vehicle ownership. The resulting trip generation table, which is displayed in Table 2, was judged to represent current Southern California conditions accurately and was considered an acceptably reliable forecasting tool for estimating the number of trips currently generated by residents of the study area.

Use of the trip rate table (Table 2) requires stratification of the households in Bell Gardens by type, income, and vehicle ownership. This was accomplished using a three-step procedure. First, households in each block group within the study area were classified by income level and type of housing unit using 1980 census data. This included detail on the number of households of each particular type (single, multiple) and the number of families in each particular income category (low, middle, high). These were used in conjunction with the distribution of household income (adjusted to 1979 values) by housing type for Los Angeles County obtained in the 1976 SCAG/CALTRANS survey. This resulted in estimates of the number of families, by income category, that live in each housing unit type. Second, the Los Angeles County statistics

TABLE 1 SUMMARY OF SOCIODEMOGRAPHIC CHARACTERISTICS

			ELDERLY (65+) POPULATION:							HOUSEHOLD INCOME:						
	CITY	POPULATION	TOTAL	%	MEDIAN AGE	WORKERS 16+ YEAR	WORK TRIPS BY PUBLIC TRANSIT %	WORKERS PER POPULATION %	ELDERLY PUBLIC TRANSIT DISABILITY %	MEAN	MEDIAN	PER CAPITA INCOME	FAMILIES BELOW POVERTY LEVEL %	HOUSEHOLDS ZERO AUTOS %	AREA (SQUARE MILES)	POPULATION DENSITY PER/MILE
1	Bell Gardens	34117	1914	5.6	22.0	9817	4.5	29	30.1	13745	12137	3796	23.1	15.2	2.4	14200
2	Bell	25450	2574	10.1	27.0	9306	6.1	37	16.0	15103	12636	5302	17.0	14.1	2.8	9100
3	Cudahy	17984	868	4.8	NA	5343	7.1	30	20.6	11900*	13900*	NA	NA	17.9	1.1	17000
4	Downey	86602	9142	10.6	34.0	40297	1.7	47	14.6	23510	20191	9339	5.3	5.5	12.8	6800
5	Huntington Park	46223	4057	8.8	25.2	16911	15.6	37	14.6	13858	11345	4498	20.4	25.7	3.0	15400
6	Los Angeles	2966850	312580	10.5	30.3	1351616	10.8	46	16.9	21715	15746	8422	13.0	17.2	463.7	6400
7	Lynwood	48548	3218	6.6	24.1	17190	5.6	35	18.2	16772	15099	4931	18.3	11.0	5.0	9700
8	Maywood	21810	1530	7.0	NA	7351	7.7	34	18.4	14700*	18900*	NA	NA	18.3	1.2	17700
9	Montebello	52929	5676	10.7	29.5	23483	5.9	44	18.3	21129	7731	7153	10.3	11.3	8.2	6500
10	Norwalk	85286	5171	6.1	26.8	35249	2.1	41	21.7	20915	19467	6276	8.3	5.2	10.9	7800
11	Pico Rivera	53459	3708	6.9	26.7	21106	3.6	39	18.4	20271	18401	5878	8.9	7.3	8.2	6500
12	South Gate	66784	7110	10.6	27.7	25215	6.2	38	15.4	17523	14825	6002	12.1	12.7	7.5	7800
13	L.A. County	7477503	738565	9.9	29.9	3373997	7.0	45	16.5	22518	17563	8317	10.5	12.7	-	-
14	California	23667902	2401006	10.1	30.0	10585675	5.8	45	14.9	22436	18248	8303	8.7	10.1	-	-

NA = Not Available
* = Estimate

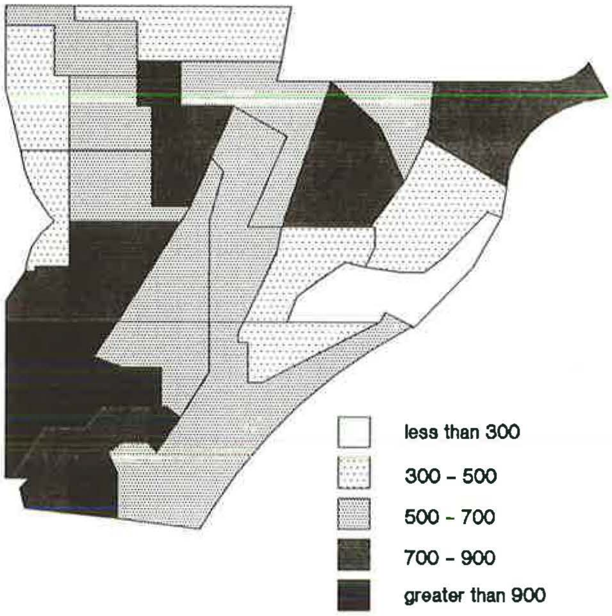

FIGURE 2 Spatial distribution of home-based work trip ends.

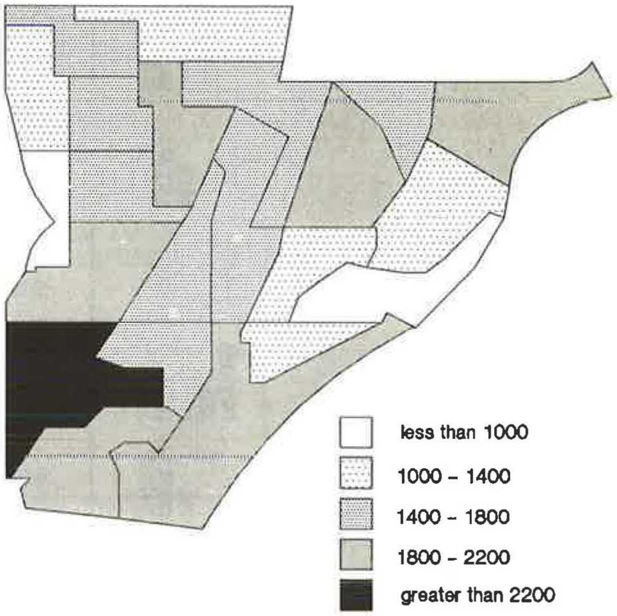

FIGURE 3 Spatial distribution of home-based nonwork trips.

TABLE 2 HOUSEHOLD TRIP GENERATION RATES (24-HOUR PERSON TRIPS)

	Income Level	S0	M0	S1	M1	S2+	M2+
Home Based	Low	0.261	0.192	0.717	1.192	1.521	1.467
Work	Middle	0.641	0.779	1.530	1.372	2.180	2.244
Trips	High	0.803	1.178	1.695	1.833	2.534	2.176
Home Based	Low	0.978	0.923	3.677	2.327	5.371	4.767
Non-Work	Middle	1.464	1.779	3.470	3.093	5.927	4.067
Trips	High	2.613	2.723	5.500	4.002	7.055	4.941
Non-Home Based	Low	0.370	0.712	1.949	1.221	2.790	3.167
Non-Work	Middle	0.669	1.573	2.214	2.372	3.140	2.911
Trips	High	1.487	2.354	2.450	2.983	4.133	3.765

where:

S0 = Single Family, Housing Units Zero Auto
M0 = Multiple Family, Housing Units Zero Auto
S1 = Single Family, Housing Units One Auto
M1 = Multiple Family, Housing Units One Auto
S2+ = Single Family, Housing Units Multiple Auto
M2+ = Multiple Family, Housing Units Multiple Auto

Source: OCTC, 1981

for households stratified by vehicle ownership and housing unit type from the 1976 SCAG/CALTRANS survey were used in conjunction with the household type and automobile ownership census data for the study area to estimate the distribution of vehicles by household type. Third, vehicle-income stratification ratios drawn from the 1976 SCAG/CALTRANS survey were used in conjunction with results from the first two steps of the procedure to produce the estimated stratification of households within the study area.

Application of the trip rates to the market segments determined by the foregoing procedure produced estimates of the trips generated by residents of the study area for various trip purposes. The geographical distributions of estimates of home-based work and nonwork trips are shown in Figures 2 and 3, respectively.

In estimating trip distribution by direction, local traffic data were used. The average ADT volumes along the four principal arteries through Bell Gardens (Gage, Florence, Eastern, and Garfield) were used to compute probabilities of trips along each of the major directions. Admittedly, this is an imprecise procedure, subject to two major sources of potential bias. First, relative ADT levels on principal roadways may primarily reflect the directional distribution of through traffic, not of Bell Gardens residents. Second, the directional distribution of automobile trips may not reflect the desired directional pattern of transit dependents. Despite these potential problems, the use of ADT data was considered to be the most reasonable approach to generating the needed directional distribution.

This assumption is somewhat ameliorated by the following considerations. Local freeways route virtually all north-south through traffic and much east-west through traffic around the study area; thus, identified ADT levels can be considered fair estimates of local demands. Examination of Figure 1 shows regional activity centers near Bell Gardens that lie along major arteries passing through the city. Interviews with several community groups identified usage of such centers that supported the directional estimate based on ADTs. No general public survey was attempted, although a small sample phone or mail-out survey could identify primary destinations outside the city proper. Finally, a more elaborate examination of traffic counts can lead to a better assessment of origin-destination flows. Such an approach is becoming a standard technique in travel modeling and forecasting.

Transit service and ridership data were obtained from the regional transit agency, the Southern California Rapid Transit District (SCRTD). The routes were plotted with 0.25-mile bands surrounding them, and all residents within the routes' catchment area were considered potential transit users. An additional factor was employed for potential trips using the 826 route. Route 826 is confined to an approximate 4- to 5-mile east-west reach, and a 1-mile north-south reach. The majority of the route is within 1 mile of the city limits and can be considered to service trips with an average distance less than or equal to 1 mile. Those parts of Route 826 beyond this distance are predominantly "covered" by either Route 828 or Route 259. Based on trip length distributions for work (1980 census) and nonwork (1976 CALTRANS/LARTS survey data) trip purposes, the 1 mile distance restriction would service 1 percent and 30 percent of work and nonwork trips, respectively. These percentages were used to adjust the "eligible" trips that could be accommodated by Route 826. Service levels for the 828 and 259 routes were adjusted to prevent double counting.

Table 3 summarizes the results of this procedure, indicating the percentage of trips that could potentially be served by transit in each zone. Estimates for nonwork trips may be quite liberal since many restrictions on mode choice (such as carrying packages for shopping trips) have been ignored. Nonetheless, proximity to transit lines is a basic determinant of transit potential.

Estimating Travel Deficits

Based on the data presented above and the procedures outlined previously, trip deficits were computed for each census block in Bell Gardens. These trip deficits (both level 1 and level 2) are displayed in Table 4 for work and nonwork trips. The numbers in this table refer to trip ends (i.e., the number of round trips between home and an activity would be equal to one-half of the totals displayed). Note that these measures represent coarse approximations to increased demand that might be achieved through provision of high-level transit service that approaches characteristics of the automobile. Such service is typically associated only with demand-responsive systems with a high density of service. The geographical distributions of these trip deficits are displayed in Figures 4 and 5.

The results indicate that the level 1 deficit for the city amounts to approximately 3,600 person trips/day, which corresponds to approximately 1,800 daily activities (or about 0.20 daily person trip per household in the city), that are foregone because of mobility restrictions associated with the absence of any automobile in the household. The level 2 deficit, which corresponds to the difference between estimated actual travel and the amount of travel that would occur if automobile availability constraints essentially were eliminated, is in excess of 18,000 person trips/day, or more than 9,000 daily activities (or 1.0 daily person trip per household).

These aggregate figures have more meaning when distributed among the households according to automobile ownership. The level 1 deficit, which impacts only those households with zero automobiles, corresponds to approximately 2.6 person trips per day for each household with zero automobiles. This, in turn, represents at least one activity per day per household impacted. Similarly, the level 2 deficits impact both zero- and one-vehicle households. These deficits correspond to approximately 5.2 and 2.6 daily person trips per household for zero- and one-vehicle households, respectively (roughly, 2 and 1 activities, respectively, per day per household impacted).

The preceding estimates of travel needs do not reflect the potential ability of existing transit services to provide mobility to Bell Gardens residents. A zone with high needs may be situated favorably relative to transit service, which would enable residents of this zone to satisfy some of their mobility needs with transit. In contrast, other zones may be poorly situated to transit, in which case their residents lack transit mobility regardless of the theoretically estimated level of needs. Thus a mechanism is needed to adjust the travel needs for the quality of transit service supplied to a zone. This adjustment procedure simply entailed determining, for each census block, the trip deficits that could not be accommodated on transit. That is, the values in Table 4 were multiplied by the

TABLE 3 TRIPS POTENTIALLY SERVED BY EXISTING TRANSIT SERVICE

Analysis Zone	Work Trips Potentially Served	Non-Work Trips Potentially Served
A1	4.0%	32.1%
A2	10.9	37.0
A3	33.0	52.4
A4	36.2	31.2
A5	26.6	38.2
A Total:	23.2	38.5
B1	0.4	10.0
B2	10.9	37.0
B3	7.2	34.2
B4	41.1	58.0
B5	13.1	38.4
B6	1.0	30.0
B Total:	10.2	31.6
C1	21.0	44.0
C2	18.1	30.0
C3	55.7	50.5
C4	53.7	50.9
C5	61.0	72.0
C6	21.1	44.0
C Total:	38.2	48.1
D1	21.0	44.0
D2	9.9	31.8
D3	19.9	40.3
D4	5.9	32.0
D5	17.9	38.9
D Total:	15.5	37.1
AREA TOTAL:	**21.6%**	**38.7%**

values in Table 3, and the results were subtracted from Table 4. The result is Table 5, a spatially disaggregated estimate of travel deficits that could or could not potentially be served by existing transit service. Figures 6 and 7 show these results graphically.

USING UNMET NEEDS ANALYSIS TO DESIGN TRANSIT SERVICE

No single transit alternative is likely to meet every transportation need identified. The more diverse the unmet needs of various user groups are, the greater will be the resulting range of necessary service alternatives. The characteristics of any proposed system must clearly fit the needs of particular markets. The purpose of the Bell Gardens transit service was to provide improved local intracommunity service and to facilitate access to the existing regional transit system. Two primary concerns were to provide better transit for work trips and to improve the mobility of elderly members of the community. Thus the elderly market and the commuter market received especially high priority. Alternate transit services are defined not only by the technology employed (e.g., bus transit, taxi, dial-a-ride, etc.), but also, and perhaps more importantly, by the level of service that technology provides. The service alternatives that were considered for Bell Gardens included:

- some form of conventional fixed-route, fixed-schedule transit (FRT),
- some form of demand-responsive transit (DRT), potentially dial-a-ride, route deviation, point deviation, or taxi (regular or shared-ride), and
- a jitney service (fixed route but variable schedule).

Various applications of fixed-route, demand-responsive, and jitney technology had the potential to satisfy portions of the total travel demand. Given this choice of feasible alternatives, the next step was to match carefully the elements of transit service options to identified needs and priorities of specific markets.

The spatial distribution of travel deficits was such that a fixed-route service did not appear capable of adequately meeting all important transit needs. As Figures 6 and 7 indicate, the zones of highest transit service adjusted trip deficits do not group along any corridor, but instead are distributed

TABLE 4 TRIP DEFICITS

CENSUS BLOCK TRACT GROUP	LEVEL 1 DEFICITS WORK TRIP DEFICIT	LEVEL 1 DEFICITS NON-WORK TRIP DEFICIT	LEVEL 1 DEFICITS TOTAL TRIP DEFICIT	LEVEL 2 DEFICITS WORK TRIP DEFICIT	LEVEL 2 DEFICITS NON-WORK TRIP DEFICIT	LEVEL 2 DEFICITS TOTAL TRIP DEFICIT
A1	25	62	87	72	231	303
A2	55	126	181	197	625	832
A3	51	123	174	189	597	786
A4	38	82	120	183	599	783
A5	122	211	333	319	1,044	1,363
TOTAL A	292	611	903	961	3,113	4,074
B1	24	53	77	159	529	688
B2	27	68	95	105	338	443
B3	9	27	36	51	161	212
B4	19	39	58	88	282	370
B5	71	135	206	268	901	1,169
B6	27	55	82	120	386	506
TOTAL B	178	377	555	791	2,595	3,386
C1	44	69	113	191	665	856
C2	71	152	223	219	708	927
C3	78	154	232	231	761	992
C4	47	97	144	213	704	917
C5	47	113	160	166	524	690
C6	63	133	196	151	633	784
TOTAL C	348	716	1,064	1,216	4,175	5,391
D1	26	49	75	140	579	719
D2	49	111	160	243	786	1,029
D3	83	174	257	277	902	1,179
D4	92	180	272	236	761	999
D5	135	259	394	471	1,568	2,039
TOTAL D	386	770	1,156	1,368	4,502	5,870
TOTAL:	**1,204**	**2,474**	**3,678**	**4,336**	**14,385**	**18,721**

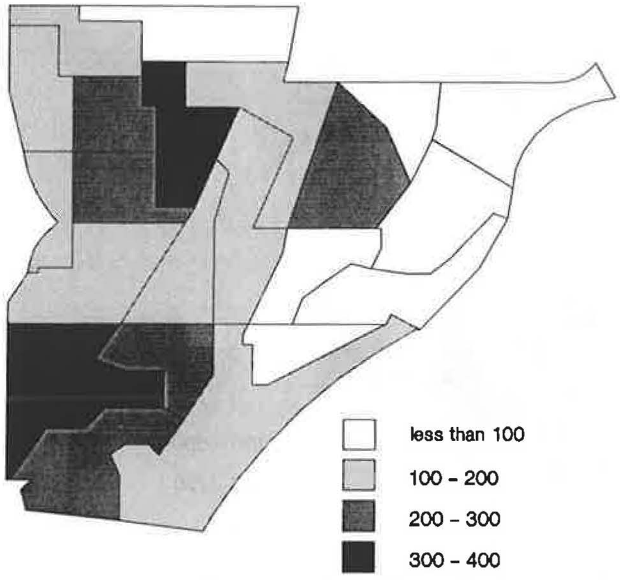

FIGURE 4 Total level 1 trip deficits.

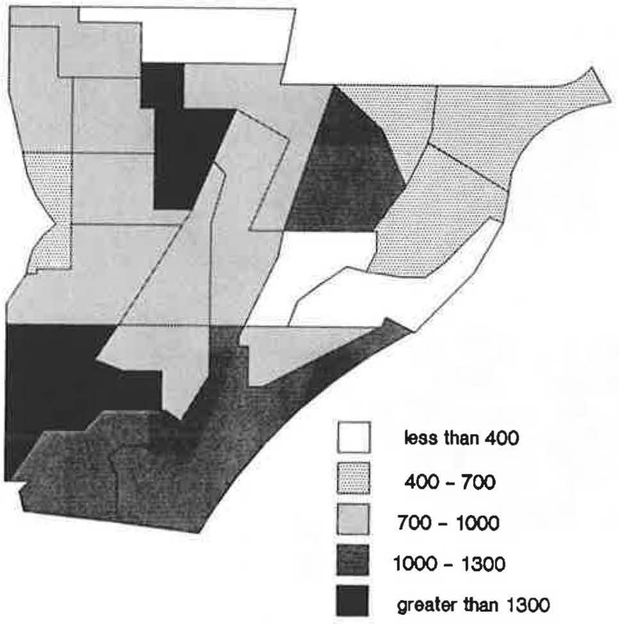

FIGURE 5 Total level 2 trip deficits.

TABLE 5 TRIP DEFICITS AND TRANSIT SERVICE

CENSUS BLOCK TRACT GROUP	LEVEL 1 DEFICITS			LEVEL 2 DEFICITS		
		POTENTIALLY SERVED			POTENTIALLY SERVED	
	NOT SERVED	Work	Non-Work	NOT SERVED	Work	Non-Work
A1	66	1	20	226	3	74
A2	128	6	47	580	21	231
A3	93	17	64	411	62	313
A4	80	14	26	530	66	187
A5	220	32	81	879	85	399
TOTAL A	587	70	238	2,626	237	1,204
B1	72	0	5	634	1	53
B2	67	3	25	307	11	125
B3	26	1	9	153	4	55
B4	27	8	23	170	36	164
B5	141	9	52	788	35	346
B6	66	0	16	389	1	116
TOTAL B	399	21	130	2,441	88	859
C1	74	9	30	523	40	293
C2	164	13	46	675	40	212
C3	111	43	78	479	129	384
C4	70	25	49	445	114	358
C5	50	29	81	212	101	377
C6	125	13	58	464	32	278
TOTAL C	594	132	342	2,798	456	1,902
D1	48	5	22	435	29	255
D2	120	5	35	755	24	250
D3	170	17	70	760	55	364
D4	209	5	58	741	14	244
D5	269	24	101	1,345	84	610
TOTAL D	816	56	286	4,036	206	1,723
TOTAL:	**2,396**	**279**	**996**	**11,901**	**987**	**5,688**

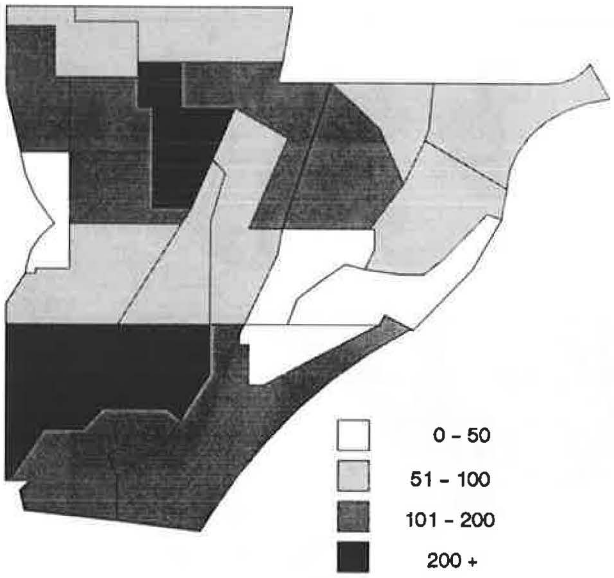

FIGURE 6 Spatial distribution of transit service adjusted level 1 trip deficits.

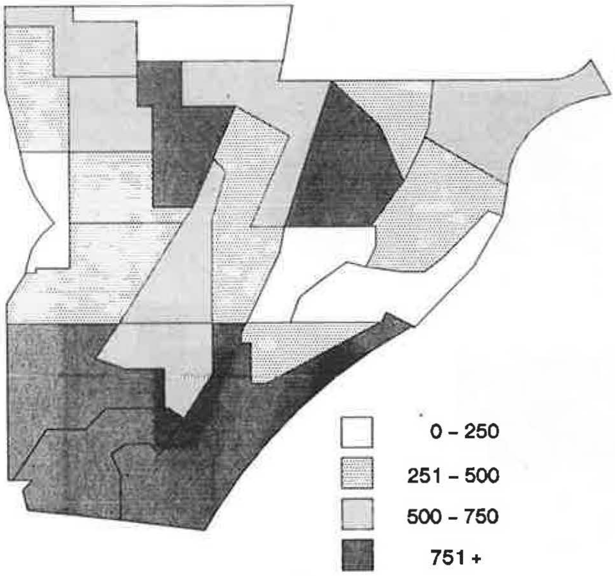

FIGURE 7 Spatial distribution of transit service adjusted level 2 trip deficits.

throughout the city. The only mode judged capable of serving this dispersed distribution of need was some form of demand-responsive transit. DRT also had the advantage that, as a flexible transit service, it could serve both work trips during the peak period (primarily as a feeder to SCRTD regional routes) and intracommunity travel by low-income and elderly persons during off-peak.

Based on these considerations, a point deviation DRT system was recommended for implementation. In this modified DRT service, on each vehicle tour, the vehicle is always routed by several fixed points in the city. Residents can request pick-up and delivery to any point in the city; alternatively, those whose origin is near the fixed points can simply walk to these locations for pick-up. The fixed points were placed in the residential areas of greatest unmet need, as determined by the previous analysis, and at a major center of community activity. Figure 8 shows the location of these points superimposed on the spatial distribution of daily transit service adjusted level 2 trip deficits, as well as an example routing of a DRT vehicle on a particular excursion.

The pricing rationale employed was to maximize social benefits derived from increased transit use. Such public benefit fares account for incremental benefit to nonusers as well in establishing a fare policy. This justifies the use of sales tax funds from Proposition A on a citywide basis. As the service is a general benefit, any fares derived should be expected to pay for only a small portion of the cost. A nominal ($0.25) flat fare was selected to (1) avoid equity problems, (2) reflect the short trip lengths of the demands to be served, (3) facilitate implementation and operation, and (4) discourage unnecessary travel that might result from a no-fare operation.

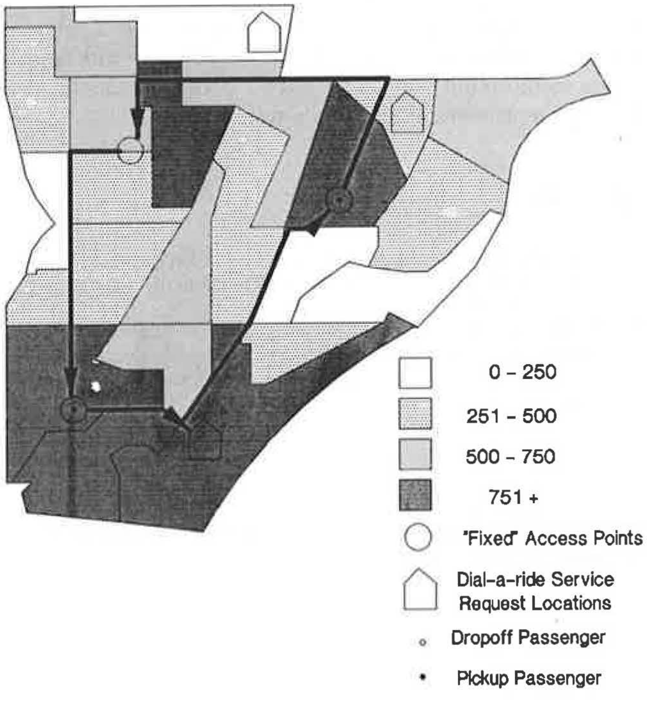

FIGURE 8 Routing of DRT service relative to distribution of transit service adjusted level trip deficits.

EVALUATION OF THE PROCEDURES

To determine whether the procedures developed previously are useful in designing transit services that respond to actual needs, a comparison between projected needs and manifest behavior is needed. This comparison was accomplished by using the geographical distribution of demand for the point deviation DRT service. For this comparison, drivers' logs for a single month were analyzed to determine the locations of all residential trip origins for the month (school trips were excluded, but they represented a small portion of all trips). This distribution of monthly rider origins (Figure 9) was then compared to both the spatially disaggregated unadjusted and transit-adjusted trip deficits.

The use of a full month of daily driver logs avoids problems associated with periodic fluctuations in demand. These monthly figures are to be correlated with unmet travel needs estimated on a daily basis, since no simple analysis can provide accurate assessments of day-to-day variability in travel demand. Standard correlation techniques, of course, properly account for the difference in scale of the estimated deficits and observed ridership.

As a means of assessing the quantitative agreement between the spatially disaggregated estimates of travel need and actual rider origins, Spearman rank-order correlations were performed. Conventional product-moment correlations (Pearson) assess the degree of linear relationship between two continuous, interval scaled variables, assuming bivariate normal populations. Rank order correlations (Spearman) avoid this burden of population distribution assumptions by converting raw data to ordinal values. On the other hand, Spearman correlations are a weaker statistic than are Pearson correlations. Neither method, however, necessarily reflects a causal relationship between the correlated variables. Specifically, the block group zones were ranked by ridership origins, level 1 travel deficit, and level 2 travel deficit, respectively; and rank-order correlations were computed. The results are shown in

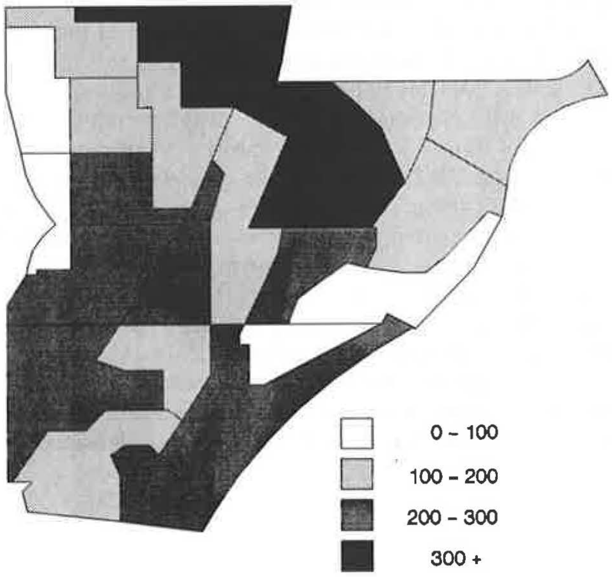

FIGURE 9 Spatial distribution of observed DRT trip origins.

TABLE 6 SPEARMAN RANK-ORDER CORRELATIONS BETWEEN RIDERSHIP AND TRIP DEFICITS

	Correlations Between:	
Ridership	Unadjusted Level 1 Trip Deficits	Unadjusted Level 2 Trip Deficits
All zonal origins	.56	.66
Excluding B1	.63	.74

	Correlations Between:	
Ridership	Transit Service Adjusted Level 1 Trip Deficits	Transit Service Adjusted Level 2 Trip Deficits
All zonal origins	.66	.80
Excluding B1	.72	.79

All correlations significant at .01 level

Table 6. Two sets of correlations were computed, one with all zones included, the other excluding zone B1. This zone had unexpectedly high ridership, and further analysis of the data revealed that 40 percent of all trips originated at two residential addresses. As no other zone exhibited a similar phenomenon of a few households marking such intensive use of the service, the ridership level of zone B1 may be an abnormality.

The results of the rank-order correlations generally support the validity of the approach to unmet travel need estimation presented here. The correlation of 0.80 between the transit service adjusted level 2 trip deficits and actual ridership indicates that the procedures result in reasonably good predictions of the spatial distribution of transit demand. It is noteworthy that adjusting the travel deficits for access to transit uniformly increased the rank-order correlations. This indicates that the extra work necessitated by this adjustment is worthwhile. A Pearson correlation of 0.73 between transit adjusted level 2 trips deficits and ridership indicates that variations in the level of absolute trip deficit explain about 53 percent of the variation in absolute zonal demand for the service.

The service implemented is primarily a demand-responsive operation, with door-to-door service. The exception is the placement of three fixed points—thus the classification as a point-deviation DRT system. As these points were selected on the basis of the needs assessment, there is some bias in the resulting evaluation, although this is somewhat tempered by the observed data that indicate trip rates comparable to similar zones without the fixed points. It is possible, but not verified, that the individuals using the fixed-point locations may be quite different from the other users of the system (e.g., individuals with English language problems).

The DRT service was designed to reflect the distribution of the identified deficits, and although aggregate demand estimates for the service closely matched actual ridership, overall ridership does not match, nor is it expected to match, needs identified relative to automobile-equivalent mobility. Although analyses of variance in other factors related to need, such as income or population density, could lead to a similarly designed and effective service, this technique also provides an assessment of residual unmet need—that is, automobile-equivalent mobility not met by implemented services.

The statistical results indicate that the procedures outlined here produce reasonably reliable estimates of the spatial distribution of need and demand for transit service. This conclusion must be qualified to the extent that the service in question was of relatively uniform quality throughout the study area, whereas fixed-route transit produces major quality differentials depending on the location of the route relative to origin and desired destination. A useful area for additional research would be the testing of these procedures, with appropriate modification to reflect service access differentials, with a newly implemented fixed-route transit service.

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Bus and Subway Integration in Seoul: A Case of Doing Nothing

LO DAGERMAN AND JAIMU WON

Public transportation provided by small private operators has attracted much attention, particularly in the developing world. In general, private services have been found to be both effective and profitable in contrast to those provided by large public systems. In many countries, public and private transportation services run side by side, which makes planning complex. An example from Seoul, South Korea, is discussed that features an exclusively private bus system and a publicly operated subway network. The two systems display quite different characteristics: the bus services were established long ago and are run by 90 predominantly small operators who are financially independent. Most of the subway is new, capital-intensive, and operated by a large public corporation that is heavily subsidized. Because the subway network was greatly expanded in 1985, the government planned to integrate the two disparate systems. The task proved so complex, however, that the government chose to do nothing. The obstacles to the integration plan are examined, and the bus companies' spontaneous adjustment to the subway expansion is reviewed. The discussion reveals how a viable strategy for planned change can be designed.

Public transportation provided by small private operators has been the subject of much attention, particularly in the developing world. In general, their services have been found to be both effective and profitable in contrast to those provided by large public systems (*1*). In many countries, public and private transportation services operate alongside each other, creating a complex planning environment. The following example from Seoul, South Korea, features an exclusively private bus system and a publicly operated subway network. The two systems display quite different characteristics: the bus services are long since established and are run by 90 operators, most of them small and financially independent; most of the subway is new, capital-intensive and operated by a large public corporation that is heavily subsidized. As the subway network was greatly expanded in 1985, the Government planned to integrate the two disparate systems. The task proved so complex, however, that the authorities chose to do nothing. This article describes the obstacles to the integration plan in detail, and examines the manner in which the bus companies have responded to the subway expansion. The objective of this paper is to contribute to a discussion dealing with the design of a workable strategy for planned change.

ORIGINAL PLAN FOR CHANGE—ITS RISE AND FALL

Seoul grew rapidly in the 1960s and 1970s. The population, which quadrupled in 13 years, now approaches 10 million. This spectacular development exerted strong pressure on the public transport system which provides 75 percent of all daily trips (*2*). Ninety private firms operate the city's bus service system, whose 363 routes and approximately 8,300 vehicles make it among the most extensive in the world (*3*. Heavy demand has resulted in historically profitable operations, with only a few rural routes receiving government subsidy. Compared to the growth of the system as a whole, the bus companies have remained small. Half of the 90 firms run three or fewer routes: 82 percent run five or fewer routes (Table 1). The average fleet size comprises fewer than 100 vehicles.

The government began subway construction in the 1970s to accommodate the fast-growing demand for transport. Late in 1985, the network was almost doubled, from 62 km to a total of 116.5 km. The costly subway system, which boasted an automated fare system, air conditioning, and artistically decorated stations, forced the issue of bus/subway integration.

The need for integration had been raised by several studies on Seoul's public transport system in anticipation of the subway expansion (*4*). Integration was not solely a matter of netting maximum returns on the subway investment by establishing proper feeder services and reducing competition from bus trunk lines, but was also meant to deal with certain inefficiencies of the bus system that had developed over time. Although the bus services indeed possess such strengths as financial self-sufficiency, availability, and affordability, there are also severe shortcomings—for example, extensive route duplication. It is estimated that more than two-thirds of routes overlap, which results in rider confusion and bus congestion in busy corridors. Another problem is long, circuitous routes (*2*).

Many transport professionals felt that the subway expansion in 1985 presented an opportunity to reexamine the entire bus network, as most bus companies would experience ridership cuts. It was estimated that 82 percent of the operators would feel the impact of ridership switching to the subway, although most companies would lose fewer than 20 percent of their riders (Table 2). The government ordered a special study with a mandate to propose detailed route revisions, as well as to make recommendations on such related issues as an integrated fare system and consolidating bus industry structure (*2*).

However, as new subway lines opened, only small changes occurred in the bus system. Adequate feeder services had not been created, trunk routes competing with the subway were left intact, and the problems of network inefficiency were left unsolved. The government had chosen to do nothing.

L. Dagerman, 1443 Green River Road, Williamstown, Mass. 01267. J. Won, Department of Urban Planning, Seoul City University, 8-3, Jeonnong-dong, Dongdaemoon-koo, Seoul, Korea 131.

TABLE 1 NUMBER OF ROUTES BY NUMBER OF COMPANIES, 1986 (*3*, pp. 119–125, 140–143)

No. of Routes	No. of Companies	% of Total	Cum.
1	6	7%	7%
2	11	12%	19%
3	25	28%	47%
4	17	19%	66%
5	14	16%	82%
6	7	8%	90%
7	3	3%	93%
8	4	4%	97%
9	3	3%	100%

Total number of routes: 363

Total number of companies: 90

Mean: 4.0 routes per company

Note: Includes routes provided by city bus (regular service) and seatbus. Seatbus offers premium service - a guaranteed seat - at a higher fare. The number of seatbus routes was 82.

It should be noted that the government in Korea is well-known for its forceful and successful interventions to promote economic growth (*5*). The construction of Seoul's subway system is an example of the city government's leadership. Why, then, did it desert the seemingly appealing plan to integrate the bus and subway systems?

FACTORS IMPEDING PLANNED CHANGE

Financial Impact on Bus Companies

Possibly the most important factor in the failure to implement the integration plan was that the government had no way of knowing exactly how it would affect bus companies. While the firms report ridership monthly and prepare annual accounts, the database is very unreliable. There are strong prejudices owing to taxes as well as other reasons (*6*).

In 1984, more than a third of the firms reported losses (Figure 1) (*2*, pp. 228–233). The operators claim that their business is declining because of competitive pressures. Car ownership, for example, has grown by 21 percent per year owing to rising incomes (*2*). Similarly, demand for taxi and specialized minibus service is up. Table 3 shows a modal split in 1985 before the subway expansion; since then the share of the bus mode has decreased by 5 to 10 percent.

At the same time as the buses' overwhelming dominance in the market is declining, operating costs have escalated and

TABLE 2 PROJECTED CHANGE IN RIDERSHIP FOLLOWING SUBWAY EXPANSION BY NUMBER OF BUS COMPANIES, 1985 (*2*, pp. 150–164)

Ridership Decrease (%)

	40%<	30-40%	20-30%	10-20%	<10%	Total
No. of Companies	5[a]	4	8	22	35	74
% of Total	6%	4%	9%	24%	39%	82%[b]

Ridership Increase (%)

	<10%	10-20%	20-30%	30-40%	40%<	Total
No. of Companies	12	1	1	0	2[a]	16
% of Total	13%	1%	1%	0	2%	17%[b]

a/ some extreme values are caused by relatively large changes to low-volume routes.

b/ these numbers do not add to 100% due to rounding off.

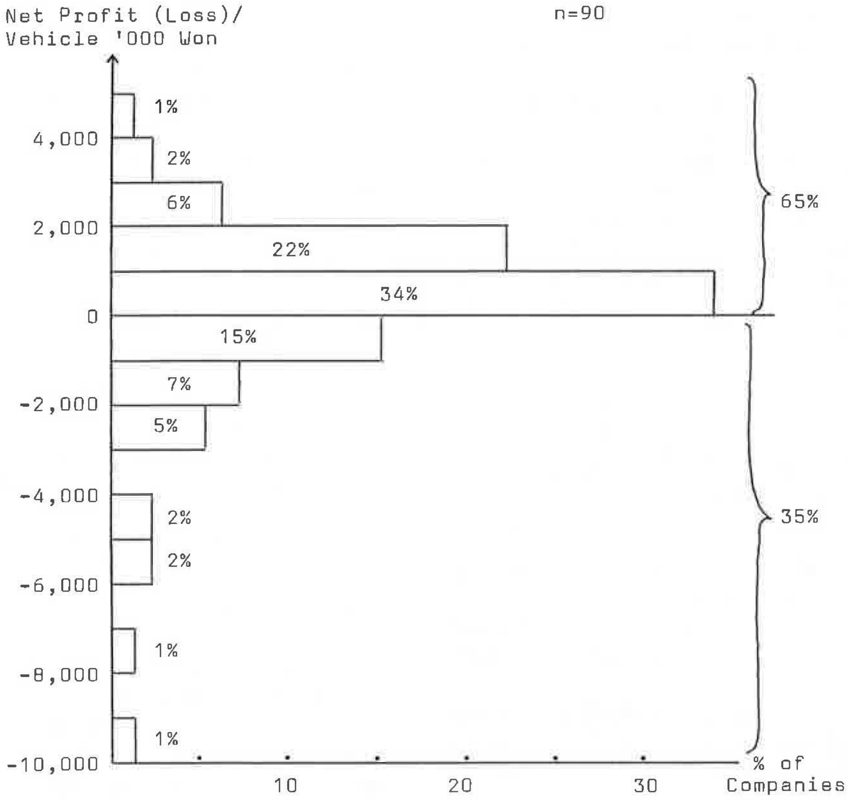

FIGURE 1 Net profit/vehicle by percentage of bus companies, 1984 (*2*).

regulated fares been kept low. The regular fare of 120 Won (about 15 cents) has remained unchanged since 1984. As the same rate applies to all urban systems across the country, operators in Seoul, where the cost of living is higher, feel particularly squeezed. The city's bus business is certainly not as profitable as formerly. However, according to the Director General of the Transportation Bureau, Seoul's bus regulating organization:

> It's hard to know if the bus companies really are losing money. There are example of money being pocketed or siphoned off. Some owners even lend money to their ailing company at a handsome interest rate. Nobody knows how vulnerable the bus companies are to change. That's the big uncertainty.

If a radical route restructuring plan carries too high a risk to firms, decision-makers must face some hard facts: the cost of subway construction will deter further expansion for years to come, and buses will remain the dominant mode of public transport. Buses provide more efficient transport than passenger cars and are crucial to a city battling congestion. Finally, the government, heavily burdened as it is by subsidizing the subway system, cannot risk having to bail out bankrupt bus operators. In other words, the City of Seoul strongly depends on the continued financial viability of the private bus firms.

Although one government objective is to reorganize the bus system and integrate it with the subway, another objective—that of preserving the bus system's self-sufficient and privately operated status—takes precedence when the two conflict.

TABLE 3 SEOUL MODAL SPLIT BEFORE SUBWAY EXPANSION, 1985 (*2*, p. 22)

	Daily Trips	Share
Intracity Bus	10,344	64.7%
Subway	1,638	10.2
Taxi	2,533	15.8
Private Car	1,487	9.3
Total	16,002	100.0%

Opposition To Change

Another important reason for the failure to implement the integration plan was that it not only lacked widespread support but also encountered strong opposition. Its only real proponent was, and is, the Subway Corporation.

This organization, under considerable pressure because of huge deficits, wants to maximize revenues and system usage. Early projections of subway ridership were "wildly optimistic," (*2*) resulting in a shortfall of one million passengers per day. In 1987, farebox revenue covered operating expenses but contributed only marginally (less than 10 percent) to capital costs. The Corporation counts ridership to grow 6–8 percent annually and counts on fare increases to substantially raise this contribution (*7*). While the growth in ridership is not expected to come from the bus system alone—there is a natural increase as well as an effort to attract car commuters—

it is clear that if the bus network were fully integrated with the subway the Subway Corporation would be better able to achieve its objective.

Although the Subway Corporation is the organization pushing for change, it is the Transportation Bureau that should lead the way for any bus route restructuring. It is responsible for licensing and regulating bus routes, assigning the location of bus stops, conducting passenger surveys, etc. (*6*). However, the Bureau lacks the motivation to change the bus system. Its mission over the years has been to guarantee the stability of the system, and to do so, the Bureau tries to assure each company of a profitable route mix (*6*):

> Thus where the relative profitability of one route is claimed by an operator to be decreasing, the City, if it accepts the operator's claim, compensates it by allowing more buses to be operated on its more profitable routes, or by allocating new routes to it which have good profit potential.

This has resulted in a route-change process driven by individual company requests and concerns. Transforming the bus system based on principles of system efficiency would demand a radical departure from the Bureau's current way of doing things.

Moreover, as the implementing agency, the Bureau would take the risk of making costly mistakes. High-risk projects are likely to be unattractive to government officials everywhere, but the rigid career paths in Korean society make officials particularly averse to risk. Hence, little initiative and even resistance to the integration plan came from the very organization which should serve as the natural leader for any such change.

The attitude of Bureau officials in part reflected their clients' (the bus companies) strong opposition to and effective lobbying against the plan. The operators' main contention was that an integrated route structure would be unprofitable; however, they also felt that the very nature of an integrated system would further infringe on their autonomy as businessmen. "Bus companies are pure private properties," says the Director of Seoul City Bus Association, "and don't want to have the government tell them what to do."

How is it in a country known for the forceful intervention by its government in economic affairs that a group of small bus company owners can be so influential? The most accurate answer rests on the fact that Seoul City depends on the continued viability of the private bus system. But another feature to the Korean system explains why bus owners get the ear of the authorities. It is a known, although undocumented fact, that during the growth in the 1960s and 1970s profitable bus routes were given as gratuities to persons close to the ruling group, such as military retirees. Therefore there are direct links between bus company owners and the ruling elite. Says the former project manager of the Government integration study, "The fact that 90 bus companies are in existence is a proof that all of them have certain political connections."

It is not clear that riders would benefit from bus/subway integration. The number of transfers would increase dramatically—one corridor study estimates as much as 40 percent—while total travel time would be reduced only marginally (*6*). Further, without combined route and fare integration, the cost of transportation to users would increase. The integration plan, if implemented, would therefore risk generating widespread rider discontent, further eroding goodwill towards the government.

The gains to the public were not evaluated in terms of reduced road congestion, air pollution, and traffic accidents. In fact, city buses in Korea have an alarmingly high accident rate; for example, an average of 1.24 accidents per bus was recorded in 1978 (*8*). However, none of these issues have generated public protest and have not engaged citizens as a lobbying group for rationalization of the bus system.

Bus Industry Structure

The fragmented nature of bus operations, as illustrated in Figure 2 (*2*, pp. 223–225, 228–233), is a factor that severely impedes major change. For one thing, it makes companies vulnerable even to very small changes (*2*):

> Given the delicate relationship of each company on its existing routes . . . , and the complexity of the route system, a radical conversion of the current system is likely to lead to . . . unprofitability for many companies.

For another, the number of players which would have to be involved in a plan for change makes such an undertaking almost impossible. Not only are there some 80 unrelated bus companies to contend with, each also has a number of stockholders with considerable say in company operations. One manager interviewed indicated that any decisions on route changes are made at regular meetings with the seven stockholders.

A study made before the subway expansion pointed out the difficulties encountered by the bus system in adjusting to changing market conditions (*6*):

> The role it [the bus system] is asked to fulfill is rapidly changing, and its weakness is in its slow adaptability under conditions of change. The major question is therefore how to devise an industry structure that preserves the best features of the current institutions while allowing for a greater level of flexibility to meet the needs of modern cities.

The government initially supported a recommendation to form 10–15 bus cooperatives in Seoul to consolidate the industry, a concept used successfully in smaller Korean cities (*9*). However, it has not gained acceptance among Seoul's operators, and has been dropped by government officials.

COMPANY RESPONSE TO THE SUBWAY EXPANSION

How severe was the effect of the subway expansion? What spontaneous responses did it trigger among the bus companies? The following attempt to answer these questions is based on interviews with Seoul City Bus Association (SCBA) and five selected companies.

The following estimate was given by the SCBA Director: "All bus companies have been affected by the subway; the difference is a matter of degrees. We estimate that 30% have experienced a drastic ridership reduction, 40% a moderate and 30% a slight reduction."

He feels, however, that there are several factors that mitigate the negative effects and reduce the pressure on operators to take radical countermeasures. For one thing, the govern-

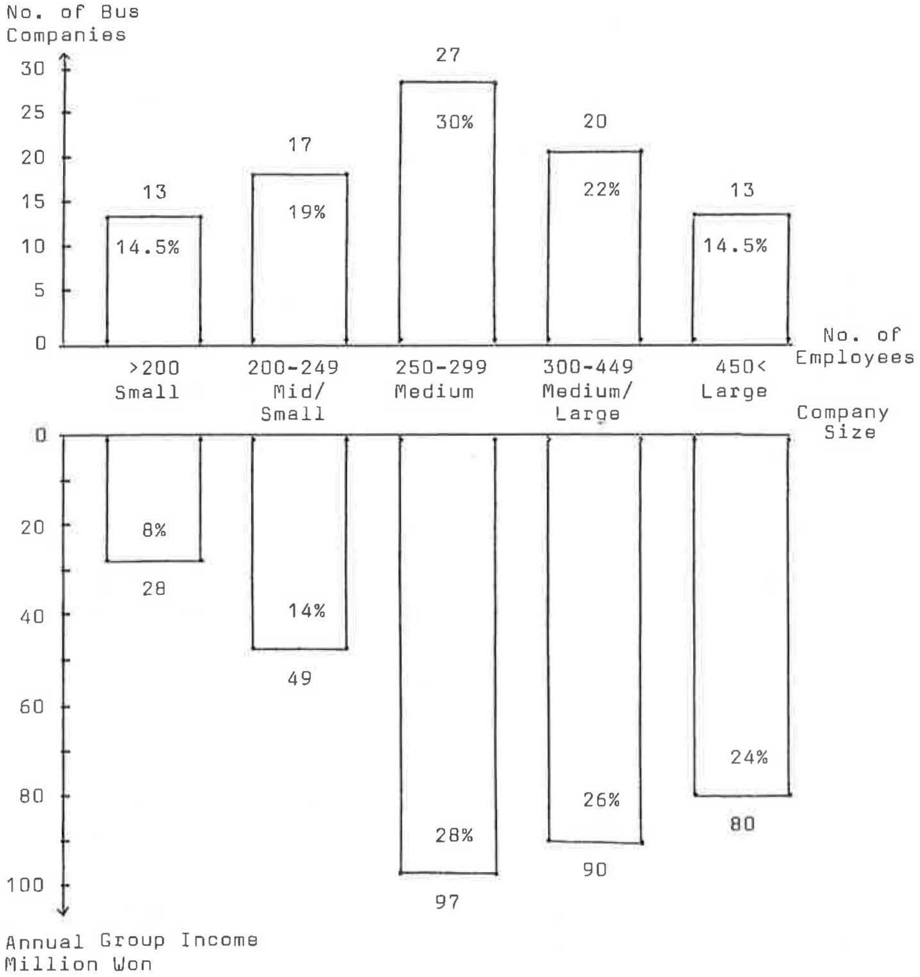

FIGURE 2 Bus company size by number of companies and annual income, 1984 (*2*).

ment has held the total number of vehicles constant since 1982, in spite of annual rider increases of 6 percent. Some companies therefore can afford a certain percentage drop in ridership without operating at a loss, according to SCBA. For another, companies expect that the government will allow a fare increase sometime within the next year. The Director's view is that most operators, at present, can weather the effects of the subway expansion. It may, however, become more critical in three to four years, when the issue of fleet replacement comes up for a large number of companies. Some firms are struggling now: these are small companies that depend on one or a few routes with significant ridership decreases, and financially troubled firms that are vulnerable to even marginal deterioration of business.

Five such companies were interviewed to get firsthand information on how they have responded to pressure for change. All operations described in Table 4 operate and depend on trunk routes that compete with a subway line opened in 1985.

Non-Radical Response

While the reported drop in ridership is similar for the five companies, three developed a non-radical response to these decreases. The response consists of traditional measures such as lobbying for a fare increase and seeking compensatory route adjustments from the Transportation Bureau.

One of the companies who used this response is Company 1, whose only route, previously very profitable, is badly affected. The company is living off the wealth that it has accumulated, but reports that business will have to improve by the time vehicle acquisition appears on the agenda.

Company 2 is equally small and dependent on a route with high ridership decline. In addition, however, it is such poor financial condition that the owners are thinking of ways to get out of the bus business, i.e., to provide taxi or minibus service. It would like the government to authorize conversion of bus permits to taxi licenses.

Company 4 is medium-sized, operates four routes and is in fair financial condition. But it shares a business development problem with the two other operators: while the new subway line basically has rendered the trunk routes obsolete, the company's depot location is such that it makes it very difficult to take advantage of new route opportunities in outlying areas.

Radical Response

The two operators that took radical action did so in different ways: one sold its operations to a larger company, the other initiated cooperative operation with a competing firm.

TABLE 4 FIVE SELECTED COMPANIES, 1984 (*2*, 150–, pp. 222–225, 228–233, 239)

Company	1.	2.	3.	4.	5.
Size[a]	small	small	mid/small	medium	medium
No. of Routes:					
Citybus	1	2	2	3	2
Seatbus	0	0	1	1	1
Riders/Day:					
Citybus	74,088	60,145	70,173	96,756	82,865
Seatbus	-	-	4,301	3,597	7,762
Fleet Size	49	53	63	92	85
Net Profit/ Vehicle '000 Won[b]	2,367	(101)	437	631	49
Debt as % of Total Assets[c]	66.8%	154.2%	187.8%	89.7%	69.5%
Financial Position	very good	poor	poor	fair	fair
Reported Ridership Decrease 1987[d]	-20%	-15%	-20%	-15%	-20%

a/ Measured by the no. of employees: >200 (small); 200-249 (mid/small); 250-299 (medium); 300-449 (medium/large); 450< (large).

b/ Median all 90 companies: about 500,000 Won. $1= about 850 Won.

c/ Mean all 90 companies: 97.9%.

d/ Based on interviews.

Company 3, which sold out, was in financially precarious condition before the subway opened. The new owner, after making managerial improvements, is operating basically the same routes at a satisfactory return. The operator plans to serve the growing demand for feeders to the subway from areas further out in the corridor. The purchase of Company 3 placed it in a strategic position to do just that.

According to SCBA, the number of companies for sale has increased. In the first months of 1987 there were five companies for sale as opposed to a total of ten since the beginning of the 1980s. The most important reasons for this increase are acute financial crisis and the perception of a declining market. Most buyers are other companies: therefore, continuing market pressures may cause spontaneous consolidation of the industry.

Company 5, which initiated cooperative operations, shared an intercity route with a competitor that faced competition from train and local bus operators in addition to the subway. The two companies that now cooperate in operating the route have maintained their profitability by cutting the number of vehicles on the route. This is a measure that, in fact, rarely is taken unilaterally by an operator. The reason is (*6*):

> . . . that there are competitive pressures on operators to run the maximum number of buses at all times, since the share of revenue along the main corridors between operators will be determined principally by the relative number of buses.

The bus cooperatives established in other Korean cities have in some cases led to both vehicle and route rationalization schemes (*9*). With the exception of the one cooperatively operated route in Seoul, the concept has won no supporters. The companies interviewed quote the number of operators and the complexity of routes as obstacles. But in truth, the pressures may not yet be sufficient to force more companies to consider joint actions.

CONCLUSION

The city government backed off from the plan in 1985 to integrate the bus and subway systems in the face of financial risk, political opposition, and bureaucratic resistance. These impediments to change are aggravated by the existence of a fragmented bus industry structure.

The government could, at the time, choose to do nothing because integration did not arise as a response to acute crisis. The financial condition of the Subway Corporation has since deteriorated, forcing the city to request assistance from the national government. Whether or not such assistance is granted, Seoul City is likely to experience increased pressure to seek maximum return on the subway investment, thus moving the issues of proper feeder services, fewer competing bus trunklines, and fare integration higher on the agenda. The Subway

Corporation approached Seoul City Bus Association with a feeder bus proposal in May 1987, a sign of the growing urgency of bringing about bus/subway integration. Not surprisingly, the proposal was immediately rejected.

Most bus companies are exposed to the changing and, in their view, declining market conditions. The government, by failing to act at the time of the subway expansion, in fact forced private operators to deal with the effects of declining ridership. Interviews conducted for this research show that some of the smaller firms are adjusting to the decline with difficulty. The consequence may well be a further increase in the number of firms for sale, resulting in a spontaneous process of industry consolidation.

The government is discussing changing its policy from one that seeks to stabilize the industry by keeping all firms in business, to one that would let less efficient operators go out of business and support consolidation. As a consequence the government is considering abolishing current tax disincentives for large operations.

The climate of increasing difficulty for small firms and the subsequent consolidation of the industry can establish the foundation for a constructive dialogue between government and bus operators on how to reorganize the bus system and achieve bus/subway integration, to secure the continuing financial viability of a privately operated bus system.

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Demand for Intercity Bus by the Rural Elderly

DANIEL SPERLING AND ROBERT GORALKA

What role could and should the intercity bus play in serving the growing elderly population in rural areas? Telephone and on-board surveys were conducted in a corridor in Northern California to learn who used intercity buses and who did not, and why. It was found that only a tiny number of elderly riders were "captive"; the remainder had similar demographic, socioeconomic, and auto accessibility characteristics to those who did not use intercity buses. This finding implies that the potential for expanding ridership may be significant, but also implies that the intercity bus does not provide an essential public service to elderly people. To understand and predict ridership, future studies of intercity bus demand should focus on the particular circumstances and lifestyles of individuals living in differing sociocultural environments, not on traditional demographic, socioeconomic, and auto accessibility indicators.

The elderly population of the United States is large and expanding (people 55 and older are projected to increase from 20.8 percent to 28.4 percent of the U.S. population between 1980 and 2020); more than 40 percent of these elderly people live in rural areas and small cities outside metropolitan areas (*1*). These elderly people have special transportation needs: besides experiencing diminishing physical mobility, they often live in remote locations and, compared with their metropolitan counterparts, are poorer and have less access to social services (*2–4*). Thus, despite reduced access to the automobile-based transportation system, their need for health and other social services continues to grow. To government they are a special problem (*5, 6*); to intercity bus companies they are an opportunity (*7*). As this elderly population grows, the question arises as to what role the intercity bus should or could play in rural areas (*8*).

Elderly bus riders and a sample of elderly residents in a corridor in Northern California were interviewed to learn which of them used intercity bus service and which do not, and why. The study had two initial objectives: (1) to specify how elderly riders are different from the larger elderly population (in terms of income, sex, education, age distribution, access to autos, etc.), and (2) to explore the potential for expanding intercity bus ridership among the elderly. The study corridor included several cities at each extreme of the corridor and rural settlements between them.

Ridership by the elderly on intercity bus in the study corridor was very low—about 3.3 passengers per vehicle-service hour. We were aware beforehand of this low level of ridership and had observed the same low patronage patterns in numerous other rural corridors in California (D. Sperling, unpublished data). What was not known and what emerged as a surprising finding of this study was that only a tiny number of riders could be characterized as "captive"; most elderly people who used intercity buses could not be readily distinguished from the much larger elderly non-user population. In other words, non-users and users had similar demographic, socioeconomic, and auto accessibility characteristics.

This finding has two implications: on the one hand, since intercity bus riders were, for the most part, like other elderly people, there is reason to believe that potential demand by the rural elderly is very large; on the other hand, the absence of a significant transit-dependent population suggests that intercity bus does not provide an essential public service.

DESCRIPTION OF THE STUDY CORRIDOR

This study of the demand for intercity bus by the elderly was conducted in a lightly populated area of Northern California (see Figure 1). At one end of the corridor is Eureka, a small city of 24,153 people on the Pacific Coast (all population figures are from the 1980 national census). At the other end of the study corridor, 150 miles to the east by road, is Redding, a somewhat larger city of 41,995 which is located on the upper edge of the rich agricultural valleys of the state. The area between Eureka and Redding is mountainous and heavily forested; the largest intermediate communities are Arcata (pop. 12,340, adjacent to Eureka), Weaverville (pop. 2787) and Blue Lake (pop. 1201). Eight other communities, all with populations less than 1000, also lie within the corridor. The total population in the corridor is about 90,000.

Redwood Empire Lines (REL) is a private bus company which has operated continuously since 1938; in recent years it has provided the only intercity bus service in the Redding-Eureka corridor. In 1985, when the surveys were conducted, REL provided twice-daily service with 14 scheduled stops between Eureka and Redding. REL's service provided access to many connecting transportation services. In Redding, transfers could be made to Amtrak, Greyhound, and Trailways buses, several airlines and a weekend-only intercity bus, as well as to the local transit services. In Eureka, transfers could be made to Greyhound, several local transit services, and a limited regional bus service (see Figure 1).

Eureka and Redding are both important regional centers. Eureka has two colleges, a major hospital, several shopping centers and various commercial businesses. Redding also provides major medical facilities, shopping centers, and commercial businesses. The nearest metropolitan centers are the

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Transportation Research Group, University of California, Davis, Calf. 95616.

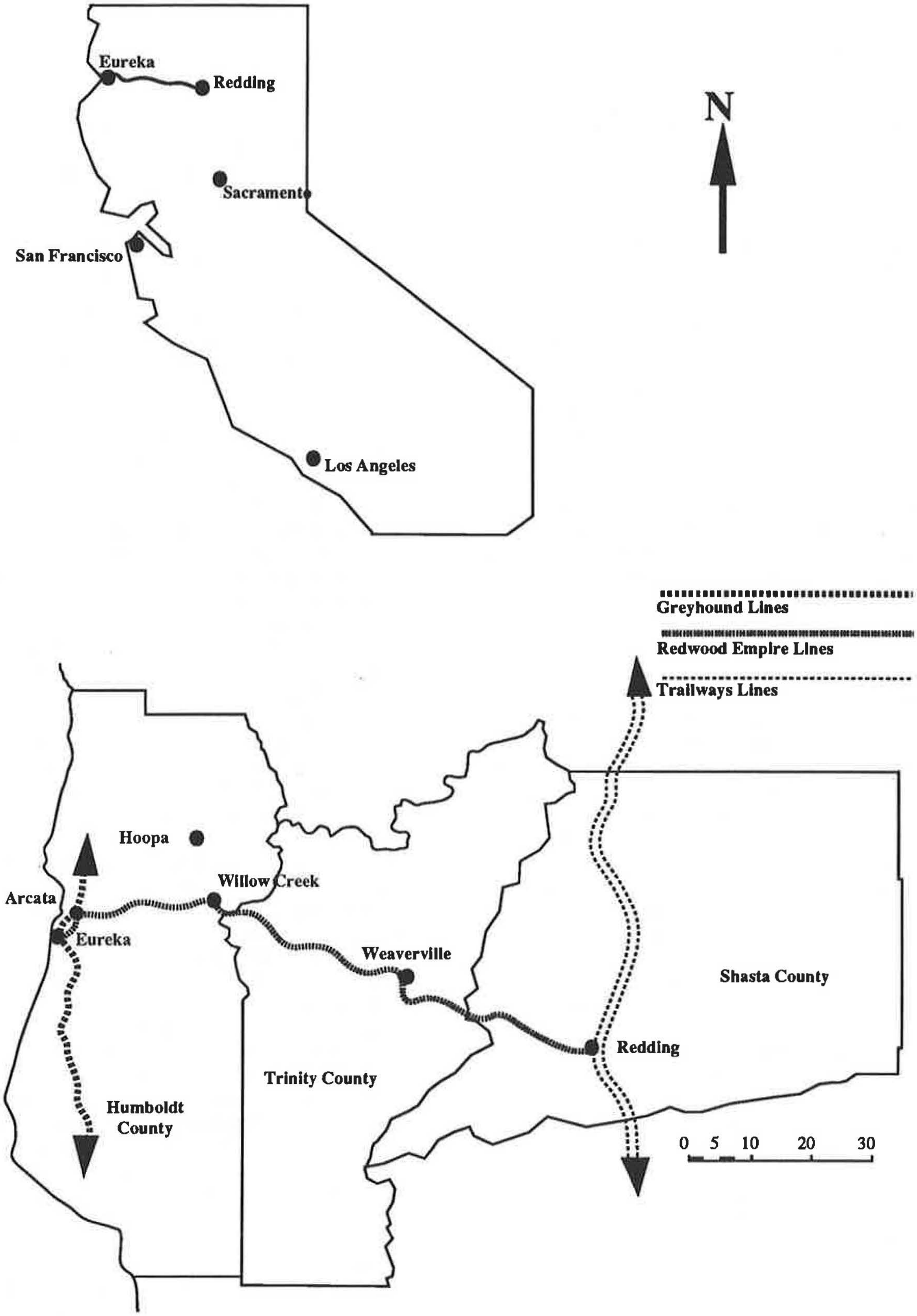

FIGURE 1 Map of study corridor, Eureka-Redding.

San Francisco Bay area, 250 miles south of Eureka, and Sacramento, 160 miles south of Redding.

RESEARCH APPROACH

To find out which elderly people use intercity buses and why, we designed two surveys: a user survey administered on the buses and a survey of elderly residents conducted by telephone.

The on-board user survey was administered during a two-week period (7–20 December 1985) to all passengers 55 or older. Since almost all trips began at or near the two ends of the route, a schedule was devised so that the interviewer could cover both of REL's runs in the same day. In doing so, the interviewer did not ride the entire route and as a result, some passengers riding to and from the intermediate rural communities may have been eliminated from the sample. These missed riders are few. A total of 69 passengers were identified; 14 refused to participate, one was sleeping, and one did not speak English, leaving 53 usable interviews. The questionnaire elicited socioeconomic and demographic data as well as information on accessibility of individuals to motor vehicles. Trip data obtained included origin and destination, other transportation modes used for the trip, travel time, trip purpose, and frequency of use of REL intercity bus service. Riders were asked to assess the quality of the transit service, and to state how or where they learned of the service.

A telephone survey of residents in the bus corridor was conducted during the same period as the user survey. The telephone-administered questionnaire was designed to resemble the on-board survey so they could be compared. The sample was drawn from telephone directories for the 14 "cities" lying along the bus route in Shasta, Trinity, and Humboldt counties (including the directory for the independent telephone company in Weaverville). Some bias was created by using telephone directories since some people, especially low-income people, do not have telephones, and others have unlisted numbers. Elderly people in convalescent hospitals and retirement homes are also missing from directories: however, the number of these missing households and individuals is estimated to be small. Altogether, 237 elderly persons were interviewed by telephone.

This sample was obtained by dialing every 20th non-business listing in each of the telephone directories comprising the study corridor. Only elderly residents (55 or older), present in about 40 percent of telephoned households, were interviewed. Call-back and replacement procedures were followed for unanswered and refused calls. The refusal rate was 18.9 percent. A lower sampling rate was used in Eureka, Arcata, and Blue Lake, with the result that residents in those areas were somewhat under-represented in the survey. Sensitivity tests indicate that our findings were not affected by the lower sampling rate in the three under-represented communities.

PREDICTORS OF DEMAND

Why do some elderly people use intercity bus service, while others do not? While an investigation of behavioral motivations was beyond the scope of this study, it was possible to identify those attributes associated with people more likely to use intercity bus service. We hypothesized that lower-income, less educated people and people without access to an automobile (i.e., those without a license and motor vehicle) would be the most likely users of intercity buses. We also tested other attributes: length of residence in domicile community, education, physical disabilities, age, sex, state of employment, and household size.

Our two surveys generated three study groups: bus riders interviewed on board the bus, bus users interviewed at home by telephone, and non-users interviewed by telephone.

A chi-square analysis was conducted to identify statistically significant differences between user and non-user populations (from the telephone survey). As shown in Table 1, we found two significant differences (at a 5 percent level of significance): non-user households were more likely to have access to a motor vehicle and to have (or have had) a driver's license. Only 3.8 percent of the non-user households did not own an automobile or truck, in contrast to 13.9 percent of the user households, and 11 percent of the non-user population did not have a current driver's license, compared to 24.1 percent of the user population. The findings were consistent with those of the on-board survey: 12.9 percent of user households did not own a vehicle (comparable to the 13.9 percent figure for telephoned users) and 22.6 percent of the on-board users did not have a driver's license (like the 24.1 percent of telephoned users). These relationships were expected; for example, an intercity bus survey in Texas found that 76 percent of riders 65 years or older owned a car, and a survey in Michigan found that 62.4 percent of "retired" riders owned at least one motor vehicle (*9, 10*). What was surprising is that these differences in accessibility to motor vehicles, measured in terms of driver's licenses and vehicle ownership, were not greater between users and non-users.

Even more surprising was the lack of differentiation with respect to other attributes. Intercity bus users were similar to non-users in age distribution, income, sex, household size, length of residence in current community, and physical disabilities (Table 1). Differences were not statistically significant at a 5 percent level of significance for any of these attributes. Of the elderly bus riders, most were under 70 years of age (61.9 percent of telephoned users and 70 percent of on-board users), but this was similar to the age distribution of elderly non-users (63.4 percent under 70). Likewise, the male-female ratio was similar for users and non-users in the telephone survey (44.3/55.7 vs. 46.2/53.8). Income was not distributed equivalently for the different groups, but there was no discernible pattern. Indeed, if anything, the users tended to be somewhat more affluent than non-users (30.6 percent of telephoned users and 14.3 percent of on-board users earned $30,000 or more compared with 12.7 percent of non-users).

Similarly, users tended to be more educated (50.7 percent of telephoned users and 39.3 percent of on-board users had completed one or more years of college vs. only 31 percent of non-users), but the relationship was not statistically significant.

Based on the telephone survey, the proportion of users who lived alone was almost identical to that of non-users (22.8 percent vs. 21 percent), although the proportion of single-person households was much greater in the on-board survey (48.4 percent).

The self-reported data on physical disabilities indicates that a somewhat smaller proportion of the telephoned users had

TABLE 1 CHI-SQUARE TESTS OF DIFFERENCES BETWEEN USERS AND NON-USERS—TELEPHONE SURVEY

Characteristic	n	D.F.	Total Chi Square	Probability	Are Differences Statistically Significance (α = 0.05%)
Income	205	3	6.64	.05<p<.10	no
Education	290	2	5.77	.05<p<.10	no
Age	303	6	8.28	.20<p<.30	no
Sex	307	1	0.48	.80<p<.90	no
Disability	308	1	1.39	.20<p<.30	no
Retirement	307	1	1.09	.20<p<.30	no
Ever Have Driver's License?	306	1	5.83	.01<p<.02	yes
Have Current Driver's License?	309	1	5.31	.02<p<.05	yes
Household Size	304	1	0.07	.07<p<.80	no
Number of Cars	301	1	7.12	.001<p<.01	yes
Length of Residence	305	3	1.80	.70<p<.80	no

disabilities that prevented them from driving an automobile than non-users (5.1 percent vs. 11.2 percent) The responses regarding transportation handicaps are consistent with those reported by T. Au and D.M.B. Baumann in a 1981 report from the Transportation Systems Center (*11*). The proportion for users surveyed on board was 12.5 percent.

The length of time a person had lived in the same community also was not a good predictor of whether a person would use intercity bus services. Users in the telephone survey tended to have lived in the same community for a somewhat longer period than non-users, but the difference was small: 25.3 percent of telephoned users (and 20.5 percent of on-board users) had lived in the community less than 10 years community vs. 20.5 percent of non-users.

OTHER SALIENT CHARACTERISTICS OF ELDERLY USERS

As in other studies of intercity bus demand (*12–14*), we found that most elderly passengers were visiting friends and relatives; 59.8 percent of on-board passengers stated this as the primary purpose of the trip. The next most common trip purposes were "recreation or entertainment" (8.8 percent), "visit doctor or dentist" (8.8 percent), personal errands (5.9 percent), shopping (2.9 percent) and work-related (2.9 percent).

Closer examination of trip patterns of on-board users provides some important insights on trip-making behavior. A large proportion of the passengers (36 percent) were traveling to or from locations outside the corridor, and had made at least one transfer to a different bus route or different mode during their trip. This non-resident user cohort contained a much higher proportion of women than did the cohort of users who resided in the corridor (15 out of 17 vs. 20 out of 33). A disproportionate number of non-corridor users also tended to be in one-person households (13 out of 16 vs. 15 out of 31). Other differences between the resident and non-resident groups (e.g., car ownership, age) were not statistically significant (see Table 2). Thus, a principal market for intercity buses appears to be trips of intermediate length—which are too long perhaps for the person to ask a friend or relative for a ride, but not long enough to justify the time and expense of traveling to out-of-the-way airports at the origin and destination ends of the trip.

To understand better who uses intercity buses, and to what extent elderly people rely on intercity bus transit, we compared frequent and infrequent riders. Frequent riders were defined as those using the REL service at least twice in two weeks (the current trip plus one previous trip). Frequent and infrequent users were similar in terms of income, sex, age, household size, and length of residence in the community. But in other important ways, the more frequent users among the elderly differed greatly from the less frequent users (see Table 3). One-fourth of the more frequent users lived in a household without a car, one-fourth had a disability that prevented them from driving, and almost one-half (43.8 percent) did not have a current driver's license. In contrast, every person in the "infrequent" group had a driver's license, lived in a household that owned a car, and were free of physical disability. The frequent elderly users also differed significantly in terms of retirement and place of residence. The frequent elderly passengers were much more likely to be retired (82 percent vs. 44 percent) and to live in outlying rural communities (44 percent vs. 0 percent) than the infrequent elderly riders. The survey therefore provides compelling evidence

TABLE 2 CHI-SQUARE TESTS OF DIFFERENCES BETWEEN PASSENGERS RESIDING IN THE CORRIDOR AND THOSE RESIDING ELSEWHERE—ON-BOARD SURVEY

Characteristic	n	D.F.	Total Chi Square	Probability	Are Differences Statistically Significant (α = 0.05%)
Income	35	3	0.54	$.90<p<.95$	no
Education	42	2	0.23	$.80<p<.90$	no
Age	45	4	0.38	$p<.95$	no
Sex	52	1	4.90	$.02<p<.05$	yes
Disability	49	1	.01	$.90<p<.95$	no
Retirement	46	1	.05	$.80<p<.90$	no
Ever Have Driver's License?	48	1	.14	$.70<p<.80$	no
Have Current Driver's License?	47	1	.69	$.30<p<.50$	no
Household Size	47	1	4.73	$.02<p<.05$	yes
Number of Cars	47	1	1.09	$.20<p<.30$	no
Car Availability	40	1	0.15	$.50<p<.70$	no

that indeed a captive population exists, but that those persons are captive not because they lack the means to afford a car, but because they have a disability and or lack a driver's license, or both. That is, they are captive because they are physically incapable of driving or lack the confidence to do so, and because they either live alone or in a household with others who also do not drive.

HOW LARGE IS THE TRANSIT-DEPENDENT ELDERLY POPULATION?

The number of elderly people in the corridor who rely on intercity transit is very small. Our on-board survey, which covered all bus trips during a full two-week period, found only about 10 people who lived in a household without a motor vehicle, and who used the intercity bus service.

Results from the telephone survey are, at first glance, at odds with those of the on-board survey. We found from the telephone survey that 5.2 percent of the elderly population in the corridor (representing about 1000 people) belonged to a household that did not own a motor vehicle. Several reasons explain why these 1000 people are not patrons of the REL service. First, most of these elderly people lived in the cities lying at the extreme ends of the corridor; most of these people do not travel in the corridor in large part because each end of the corridor lies in the hinterland of a different and much larger city—San Francisco in the case of Eureka/Arcata, and Sacramento in the case of Redding. In our telephone survey, the 14 percent of respondents who lived outside the three cities represented 46 percent of the REL users. Second, four percent of the telephone respondents indicated that in addition to not owning a car, they also had a physical disability which prevented them from using buses. Indeed, many people with disabilities find it easier or are more comfortable using a car than a bus. These two explanations narrow the list of 1000 potential captive riders in the corridor to perhaps 300 or so. Of these 300, a large proportion rely on neighbors, friends, and relatives for transportation. Our telephone survey found that of 43 respondents who were either auto-handicapped, without a driver's license, or without a vehicle, and who remembered the last trip they took in the corridor, fully 27 had relied on a friend or relative for transport on that trip. Only two had used a bus.

We cannot precisely specify the size of the captive population that travels in the corridor, but evidence from the surveys suggest that it is minuscule—less than one percent. The lesson seems to be that the automobile truly is ubiquitous; ownership is no longer a question of income. Almost all elderly people either have access to a car or have close friends and relatives that are willing to provide transportation.

These findings suggest that intercity bus may not provide an essential public service to the rural elderly; that is to say, there is no large disadvantaged elderly population in rural areas that depends on intercity bus service for transportation.

MARKET POTENTIAL

We have suggested that the captive ridership for intercity bus service is very small. Intercity bus companies cannot expect

TABLE 3 CHI-SQUARE TESTS OF DIFFERENCES BETWEEN FREQUENT AND INFREQUENT USERS—ON-BOARD SURVEY

Characteristic	n	D.F.	Total Chi Square	Probability	Are Differences Statistically Significant (α = 0.05%)
Income	21	3	2.18	$.50<p<.70$	no
Education	28	2	0.42	$.80<p<.90$	no
Sex	33	1	0.008	$p>.99$	no
Age	30	6	4.98	$.50<p<.70$	no
Disability	32	1	4.03	$.02<p<.05$	yes
Retirement	34	1	4.86	$.02<p<.05$	yes
Have Current Driver's License	36	1	10.86	$p<.001$	yes
Household Size	31	1	2.64	$.10<p<.20$	no
Number of Cars	31	1	4.31	$.02<p<.05$	yes
Length of Residence	47	1	3.82	$.05<p.<.10$	no

to draw ridership principally from the rural poor or the rural elderly. Today's market for intercity buses is not determined by socioeconomic or demographic attributes, or even auto accessibility. In today's automobile-saturated society, the market for intercity buses is largely based on circumstances: that is, the potential market for intercity buses depends on providing convenience, comfort, and competitive fares. Clearly, intercity bus companies are not competitive with the automobile across the entire population, but buses can be attractive to certain people in certain situations: those living near a bus stop or with a destination near a bus route and who do not place a high value on time. Many people might fit these criteria, especially elderly, retired people.

FUTURE RESEARCH

In view of these findings, why is ridership on intercity buses in the Redding-Eureka corridor (and in the United States in general) so low? Part of the explanation is that the elderly travel less than younger people, and that access to buses is low in rural areas because of the low population density. A more comprehensive answer, we believe, stems from on a combination of individual and social, or sociocultural factors. Most people in the United States, especially those in rural areas, have little or no experience with modes of transportation other than automobiles and light trucks. We therefore hypothesize that some rural people are actively or passively resistant to major changes in their travel behavior, and perhaps intimidated by the unknowns of intercity bus travel.

Some evidence supporting this hypothesis is provided by our surveys. We asked riders and telephone respondents how they learned of REL's bus service. The differences between users and non-users is revealing. Telephone respondents who had never used the REL service, but were aware of it, mostly learned of it via newspaper (21 percent) or by seeing the bus or bus stops (about 50 percent). Fewer than one-fourth of the respondents learned of the service from friends or relatives. In contrast, of telephone respondents who had used the bus, more than 70 percent learned of it from friends and relatives (and, in most cases from other sources as well). The on-board bus users were also introduced to the bus primarily by friends and relatives (78 percent). While this is not definitive evidence, it does suggest that elderly people (and possibly others) in rural areas and small cities are reluctant to use a bus unless introduced to it by someone they know (*15, 16*).

Other evidence that the use of intercity buses is an unfamiliar and intimidating experience is provided by the income and educational levels of the bus users. As reported earlier, there was a tendency (not statistically significant) for the users to be better educated and more affluent than the general population. This unexpected relationship can perhaps be explained by the likelihood that better educated and more affluent people explore the various options available and attempt new experiences in resolving a particular problem or situation.

Unfortunately, we did not design the questionnaire to accommodate exploring market potential from this perspective of culture and individual life experiences. We followed the conventional practice of travel demand analysis studies in attempting to identify personal characteristics of elderly people that would be good predictors of demand. That approach is not fruitful. Future investigations of intercity bus demand should investigate individual circumstances and lifestyles of elderly people living in differing sociocultural environments and should rely at least in part on less structured survey formats such as focus group interviews.

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Organization of Urban Public Transport in France: Lessons for Developing Countries

SLOBODAN MITRIC

After decades of vacillating between the extremes of government and private ownership, culminating in a steady decline in services and patronage during 1960s, urban public transport in France underwent a series of institutional reforms in the early 1970s, leading to remarkable improvements in the quality and quantity of services offered, as well as in usage. The system which has evolved over the past 15 years is a private/public hybrid: most operators are private, selected through competitive bidding every five years; all other aspects—the ownership of equipment and facilities, the establishment of routes, tariffs and service specifications, the power to impose on local enterprises a dedicated transport tax, and to make investment decisions—belong to intercommunal, areawide public transport authorities, made up of elected officials from constituent communes. Five elements of the French approach are especially relevant to urban public transport in developing countries: (i) system coherence, whereby all aspects of the system are related to each other and covered in an explicit policy; (ii) the contracting approach, fostering a quid pro quo relationship among all private and public actors involved; (iii) the preservation of competition, to maintain efficiency in providing services; (iv) decentralization, which helps balance out local demands and resources; and (v) the stability of the non-tariff revenues, which permit orderly development over time.

This paper will review the French approach to the organisation of the urban public transport sector (hereafter called transit), so as to emphasize those concepts and practices which may prove useful in working on transit problems in developing countries, particularly in some African countries whose administrative structures resemble those of France. Unless otherwise specified, the paper will refer to the French provincial cities only, the case of Paris being quite special and deserving separate treatment.

The paper concludes that of the five key elements contributing to the revival of transit in France over the last 15 years (the coherence of the institutional system, the contracting approach, the role of private enterprise, political decentralization and the selection of the major source of finance), the first three are recommended for use in developing countries, whereas the last two have problematic aspects and should be considered on a case-by-case basis.

BACKGROUND

The rapid growth in car ownership and use in the 1960s led to a crisis of public transport in French cities: operators, mostly private bus companies working on a franchise basis, reacted to the loss of patronage by reducing the supply and quality of services, and by not renewing fleets and facilities—the usual vicious circle, leading to even lower transit usage and eventual bankruptcy (*1*). In the early 1970s, the automobile was king in France: ambitious plans drawn up by the powerful caste of civil engineers, united in spirit with the even more powerful auto industry, called for no fewer than 15 new radial highways coming into Paris, based on projected "needs"; one bank of the River Seine was paved into an express highway, the other having been saved from a similar fate by the country's top politicos, once alerted to potential loss of a national heritage. Transit seemed destined to survive in a minimal, state-animated form, a bone tossed to the unfortunate.

Yet little more than a decade later, French cities boast transit systems ranking among the world's very best. While there are several showcase rail-based systems (new metros in Lyon, Lille, and Marseille; new light-rail lines in Nantes and Grenoble), the street bus is the workhorse of some 100 provincial transit networks in France (including cities of more than 30,000 people). Though operating on city streets, most often without exclusive bus lanes or priority at intersections, these bus networks provide extensive, frequent, punctual services. Their vehicles are well-maintained and their fleets regularly renewed; much use is made of information-processing tools to schedule, monitor and control operations, and to provide passenger information; interline and intermodal integration is advanced, as is integration of tariffs within and often beyond urban areas. After a steady decline in both services and clientele throughout 1960s and early 1970s, transit rebounded, posting a 50 percent increase in trips served in the 1975-84 period—a response to a 60 percent increase in vehicle-kms of service offered (*2*). Highway investment slowed, with funds shifting to street maintenance and network management; city centers blossomed around the twin arrangements of transit terminals and walk-only areas and corridors.

That France succeeded in carrying out a transit renaissance on such a scale and in such a short time reflects a consensus, across the political spectrum, on the importance of maintaining an attractive alternative to private car, as well as the tremendous technical and financial capacity that the country possesses. Yet, however impressive the fully automatic operation of the metro in Lille, or the functional design of the bus/tramway interchange points in Nantes, or the coordinated control of transit and traffic in Nancy, the most striking aspect of French transit lies not in its technical achievements, but in the institutional arrangements. It is this aspect which holds interest for transit in developing countries. While most of these countries do not command either financial resources or

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trained personnel to construct and operate sophisticated transit systems (independently of whether or not these systems have a financial/economic justification), they all need paradigms for organizing the transit sector.

Several such paradigms exist: one frequently tried approach involves municipal bus companies charging low, "social" fares and depending to a large degree on the decisions and financial support of the central government; another approach would treat transit primarily as a commercial activity, insisting on full cost recovery from the farebox and placing faith in small-size, privately owned enterprises competing in both price and service dimensions. The French system is a hybrid: it is animated and guided from the central government, but the decision-making and the finance for all but the largest systems are local; vehicles, equipment and facilities are in public ownership, but the operators are mainly private companies; the general framework of the sector is defined through laws and decrees issued in Paris, but the specific relationships among various public and private sectors are regulated through a system of renewable contracts, some of which are based on competitive bidding.

In the next section, key elements of the French approach to transit will be reviewed; the final section will highlight those aspects which may interest developing countries, many of which are in the process of creating an urban transport policy. The design of the institutional framework and the relationships within will be emphasized, rather than the details of performance. In this connection, the current preoccupation in France with reversing the past trend in transit finance, in which the travelers have been bearing progressively lower and lower load, is of little interest to this account; the regulatory system is flexible enough to permit this share to vary substantially among transit properties (see paragraph "Financing"). This flexibility is also reflected in the different ways local communities use the available sources of finance for capital investments and the changes in this financing mix over time, all of which come out of local political negotiations (*2, 3*).

TRANSIT ORGANIZATION IN FRANCE

Legislative Framework

The present organization of transit, indeed of urban transport in general, represents the cumulative effect of four laws and related decrees passed since 1973 (*1,4,5,6*):

(1) *Law No. 73-640 of 11 July 1973*, which allowed local governments to levy *versement transport*, a tax dedicated to transit, which was to provide the major funding source to fuel the resurrection of this mode;

(2) *Law No. 79-475 of 19 June 1979* (*Loi relative au Transports Publics d'Intérêt Local*), which clarified the relative roles of local and central authorities in connection with transit, and established specific contract types for transit properties (although these constraints have since been removed);

(3) *Law No. 82-1153 of 30 December 1982* (*Loi d'Orientation des Transports Intérieurs*) which established basic principles of transport sector management, e.g., defined social character of urban transport services, confirmed the supremacy of local authorities in transit, stressed contractual relationships between various actors in the sector, guaranteed fair remuneration of transport operators for services provided, etc., and;

(4) *Law No. 83-8 of 7 January 1983* (*Répartition des Compétences entre les Communes, les Départements, les Régions et l'Etat*) which established the principles and procedures for transfer of authority, property and means of finance from central to local/regional authorities.

The four key aspects of the French transit organization will now be reviewed, namely—the role of local government; the modes of operating transit properties; the sources of finance; and the approach to integrating transit with urban transport management and planning.

The Role of Local Government

The local governments in France have complete jurisdiction over transit services and disposition of financial means needed. The most typical institutional form is that of the association of communes, basic administrative units making up an urban area, into an organizing authority (AO) for transit, and other functions (*4,7*). An AO consists of elected officials from its constituent communes. Occasionally, a city is governed by a single commune (Marseilles); or, several small cities in a region may form a single AO, with the number of communes reaching several dozen. The geographical limits within which an AO exercises its powers, *le périmètre des transports urbains,* do not have to coincide with territorial limits of the associated communes, and serve purely to divide urban from interurban transport links. Once several communes form an AO, they give up their power to make unilateral decisions concerning transit (except in matters related to traffic regulation for which the jurisdiction is kept by individual communes).

The AOs can take several forms:

(1) *an Inter-communal Syndicate*: association of communes for managing transit and possibly other urban services;

(2) *an Urban District:* association of communes responsible by statute for fire services and housing, to which other responsibilities (including transit) can be added on an elective basis; and

(3) *an Urban Community* (*communauté urbaine*), responsible by statute for the ensemble of urban public infrastructure and services, including transit, parking, streets, traffic signals, etc.; other responsibilities can be added on elective basis by decision of the relevant commune councils.

The AOs are legal owners of all transit vehicles, facilities and equipment, and are empowered to do the following:

(1) impose *versement transport* (VT), the local tax earmarked exclusively for transit finance (see sections headed "Financing through Transit Operators");

(2) make all the investment decisions;

(3) define transit policies, including all service specifications and tariffs;

(4) organize transit services whether by force-account (*en régie*) or through contracts with (private) transit operators; and

(5) enter into contract with the central government to get

grants for transit system development (*contrats de dével-oppement*) in exchange for diverse conditionalities related to transit policies, services offered and the program execution.

In addition to the influence exerted through development contracts and public loans, the overall policies expressed through laws and decrees, and the technical assistance to AOs, the central government also regulates two aspects important for transit financing: (1) it sets the maximum annual rates of tariff changes, and (2) it sets the maximum rates of the VT tax.

Financing

Transit tariffs in France cover, in the aggregate, only about 50 percent of direct operating costs (*2*); for individual transit properties, this ratio varies from a low close to 20 percent, to a high exceeding 90 percent (*8*). Several factors are at work here:

(1) social policy to keep fares well under levels needed for cost-recovery, the justification including a desire to affect modal choice in favor of transit (against the private car), redistribution of income objectives, and intention to tax the benefits accruing to non-users (employers, merchants, real estate owners, car drivers);

(2) sharp escalation of operating costs (2.2 percent per year in real terms between 1975 and 1983), due to increased wages and fuel costs; and

(3) rapid expansion in routes and services where demand response is lagging (or will never materialize at the level necessary to cover costs).

What tariffs do not cover is made up by subsidies, the key source being the local transport tax, *versement transport* (VT) (*6, 9*). Indeed, the VT has proved to be the engine driving the development of transit in France over the last 15 years. In the early 1980s, it provided the finance to cover about one-third of combined operating and investment costs of transit companies in provincial cities. Instituted in 1971 for the Paris region, VT was extended (at the discretion of the local AO) to cities of 300,000 and more. This threshold has been reduced twice more: to 100,000 inhabitants in 1974 and to 30,000 in 1983. The tax is levied on all enterprises within the transport perimeter employing more than 9 people. The maximum rates are 2 percent in Paris and nearby suburbs; 1.2 percent in outer Paris suburbs (*grande couronne*); 1 percent for provincial cities of more than 100,000 people (but this is increased to 1.5 percent if the AO decides to invest in a large-scale project—tramway or metro); 0.5 percent for cities between 30,000 and 100,000 people. The tax base is salary mass up to a ceiling established for social security payments.

The VT is a dedicated, non-fiscal resource (in the sense that it can be accumulated and that it is instituted by a decision of an AO, outside the political decision-making process normal for other local taxes). It is deducted together with other social security charges (health, pension, etc.). Its statutory uses include the following:

(1) compensation for tariff reductions benefiting salaried workers;

(2) financing investments in new vehicles, infrastructure and equipment, as well as for annuities on debts related to past investments;

(3) financing improvements, reorganizations, extensions or introduction of new services (including promotion); and

(4) financing operating deficits (since 1982).

In 1975, only 26 agglomerations had introduced the VT; this number increased to 53 in 1983. The amount of funds collected has been large: in constant 1984 FF, VT brought in about FF 950 million ($109 million in 1984 terms) in 1975; by 1977, this exploded to FF 2,480 million ($285 million), hereafter increasing at a slower rate to FF 3,750 million in 1984 ($430 million). In 1984, the contributions varied from about FF 98 ($11) about FF 343 ($39) per inhabitant, depending on

TABLE 1 AMOUNTS OF VT TAX COLLECTED IN CITIES OVER 250,000 INHABITANTS (*8, 10*)

	1982 Population (000)		Versement Transport (FF million) c/				
Urban Area	a/	b/	1978	1979	1980	1981	1982
Bordeaux	640	589	49.30	62.80	78.54	87.84	111.49
Clermont-Ferrand	256	240	19.15	29.51	46.40	54.10	62.21
Grenoble	392	363	44.47	50.63	57.03	61.47	71.92
Lille	936	1048	124.49	179.61	218.28	227.20	252.67
Lyon	1221	1106	206.41	241.84	270.40	303.28	336.70
Marseille	1111	874	136.60	130.10	145.10	158.04	214.20
Montpellier	221	248	15.50	21.10	23.60	29.66	40.50
Nantes	465	465	47.28	49.10	53.00	66.60	113.00
Nice	449	337	23.40	26.54	29.60	41.60	51.51
Rennes	234	275	23.22	28.75	36.71	49.90	55.95
Strasbourg	373	406	40.50	42.15	51.80	63.12	69.60
Toulon	410	299	15.11	16.58	28.70	35.53	37.48
Toulouse	541	553	55.00	59.88	68.03	78.96	91.03
Tours	263	227	22.31	26.06	31.05	38.19	44.60
Valenciennes	350	297	21.43	29.24	30.96	36.54	40.35

a/ Agglomeration

b/ Within urban transport perimètre

c/ In current terms; exchange rates in FF to $ were: 4.51 (1978), 4.25 (1979), 4.23 (1980), 5.43 (1981) and 6.57 (1982).

the urban area, with an average of FF 236 ($27). Table 1 shows the actual amounts of VT collected in the largest provincial cities.

The application of the VT yield changed over time: between 1975 and 1982, the proportion used to subsidize operating costs varied from 40 to 47 percent, but increased to 60 percent in 1983, the first full year after the use of VT funds had been legally extended to any transit-related need, investments and operating deficits alike.

In addition to traffic revenues and the VT, sources of the transit finance include the following:

(1) "normal" fiscal resources of local communities;
(2) loans from Fonds de Developpement Economique et Sociale; and
(3) state grants for large-scale investments (40 percent for metros, 50 percent for tramways). In some cities, these grants are given through a system of development contracts signed between the Ministry of Transport and AOs for 2–3 years (renewable), with conditions depending on the extent and pace of transit development in the agglomeration.

It is a striking fact that transit subsidies in France are a very much a local matter. According to unpublished 1980 data from Centre d'Etudes des Transports Urbains, in provincial cities which instituted the VT tax, transit operating costs were covered as follows:

Source	*Percent*
Traffic revenues	54
VT tax	27
Local fiscal sources	19

For 100 provincial networks, the sources of finance for aggregated operating and investment costs were (in 1980 millions of francs and dollars):

Source	*Percent*	*Francs*	*Dollars*
Traffic revenues	32	1,859	439
VT tax	33	1,925	455
Local fiscal sources	15	863	204
Loans	15	885	209
State grants	5	324	77
	100	5,856	1,384

It is also of interest to see the application of the above funds:

Application	*Percent*	*Francs*	*Dollars*
Operating costs	60	3,520	832
Buses, depots, equipment	12	720	170
Streets and traffic	4	210	50
Metros, tramways	14	800	189
Loan annuities	9	550	130
Compensation SNCF and non-urban	1	56	13
	100	5,856	1,384

It should be noted that there exist transit systems which operate on force account without relying on the VT tax, for example the public company of Saint-Malo, where the ratio of revenues to direct operating costs is 84 percent, the rest of funds coming from the communal budget.

Due to the combined effects of substantial investments in capacity over the past 10 years (i.e., considerably increased loan repayments), the decline in the proportion of costs financed through traffic revenue, steady increases in operating costs, and the stagnation of the yield of the VT tax (in turn due to economic stagnation in France), the transit system is starting to feel the financial pinch. The tendency to tap conventional urban tax resources is quite pronounced (*6*). The root causes lie in past pursuit of a subsidy approach without sufficient controls to maintain efficiency and financial discipline; key examples cited by the critics include irresponsible, politically motivated tariff policies (imposed by the central government), unbridled investments made by AOs for the development of new lines, and padded labor contracts (*11*). Evidence appears to support the critics and a debate is underway to find ways to economize on spending and look for new sources of finance, as well as develop better techniques for financial planning (*12, 13*).

Transit Operators

Of the more than 100 transit networks in France (referring to cities with more than 30,000 inhabitants), about 20 percent are operated by the AOs on force account; the largest of these public companies is Régie Autonome des Transports Parisiens (RATP). The remaining 80 percent are operated by private companies under contracts with AOs. The contracts, usually for a 5-year period, are awarded through competitive bidding.

A large part of the market is divided among the following three private companies (*14*):

(1) TRANSEXEL, which operates some 30 networks (including subways in Lille and Lyon);
(2) SCET, with 15 networks; and
(3) CGFTE, with 8 networks.

Each of the three key operators has a somewhat different organizational approach. The TRANSEXEL typically sets up subsidiary companies in individual cities: these companies then enter into contract with AOs. The CGFTE uses a more centralized approach, involving the head office and branch offices. The SCET introduced a system of mixed-economy (public/private) companies for each network: the shareholders include the AOs, chambers of commerce, banks and (through a symbolic contribution to capital) the SCET itself. Each of these city-based companies signs a service contract with an appropriate AO, as well as a technical assistance contract with the SCET. The main advantage of the SCET approach is that it involves direct participation (*contact organique*) of the elected officials (AOs) in managing transit, while the private nature of the company permits it to operate in ways normally not open to publicly owned enterprises. The three operators show other differences as well: for example, the TRANSEXEL is very keen on marketing, the CGFTE stresses engineering skills and, generally, the supply side of the operation, while the SCET has an integrative, urban management-type orientation. In either case, the engineering and managerial knowledge amassed by these operators is considerable and its vertical integration through mother-firms is a laudable achievement. Another type of integration of all private operators is achieved through membership in Union des Transports Publics, which acts as an information clearing house and lobbying organization, as well as a body for collective bargaining with workers' unions.

Contracts between AOs and operators specify the services to be provided and divide the responsibilities and risks with regard to investments, operating costs, and receipts. This involves listing the following:

(1) route network to be served, as well as quantitative and qualitative description of services;
(2) rules for adjusting service specifications in the course of the contract;
(3) tariffs to be charged;
(4) means to be provided by each party (in parallel with the contract, a program of investments and other actions may be, but is not always developed);
(5) renumeration for services and rules for adjusting these (whether to respond to inflation, or to adjust for marginal changes in the services offered); and
(6) details of contract supervision, arbitration, start and end of contract period, etc.

Though four contract types were prescribed by law in 1979, only two types have taken root (*15*):

(1) Fixed-ceiling (*prix forfaitaire*) contract: an agreement to pay the operator a fee based on unit cost (per bus-km) and the amount of bus-km of service to be supplied; risks on the cost side are thus borne by the operator, but all investment and commercial risks are taken by the AO; in practice, such contracts also include marginal fees to pay for changes in supply demanded by the AO, as well as incentive formulas meant to increase revenues.
(2) Management Contracts (*contrat de gérance*): this has been the most popular contract type; the AO takes all the risks, paying the operator his actual expenses, based on a provisional budget which can be revised in the course of the year; in addition, there is a bonus for good management.

Since the contracts described above have not been sufficiently conducive to increased productivity of operations, new types of contract are being sought, with a goal of more balanced risk-sharing between the two parties (*16*). So far, this search has not produced any substantial innovation. In some smaller cities, contracts have been signed in which operators have undertaken both cost and revenue risks but within a very narrow band, based on inflexible service specifications and numerous safeguard clauses for the operator (including renegotiating before the normal contract period expires).

Integration of Urban Transport

The creation of AOs for transit, the introduction of the VT tax, and the subsequent development of transit in French cities took place with relatively weak links to vitally related processes of traffic management, road planning, and urban development. This is not to say that complementary developments in traffic management, road planning, and urbanization have not occurred: witness the numerous French cities with bus priority signals and lanes (even exclusive bus bridges, as in Nantes); the decrease in state aid for highway construction and a shift of local resources away from road construction towards traffic operations and road maintenance; as well as the explosion of investments in downtown renewal tied to large-scale transit projects. What was absent, however, were formal tools and processes for integrating all urban transport planning and management (as opposed to planning by mode) and establishing links to the public and private decision-making related to urbanization (*17*). Most urban general plans in France were made about 1970; though outdated (in concepts, policies and numerical side) they are still the only documents with legal weight. Traffic circulation plans carried out in numerous cities in the 1970s with state subsidies (about 50 percent) had integrative elements, but on a minor scale. The division of jurisdictions (AOs responsible for transit, communes for urban streets and traffic, the state for national roads) made it difficult to deal with intermodal relations, essentially on a case-by-case basis.

The law of 30 December 1982 (referred to previously) created a tool meant to fill this void, a new type of urban transport plan, *plan de déplacement urbains* (PDU), with the following main features (*18–21*):

(1) PDUs are multimodal (including walking) and consist of general principles, policies, management programs and development plans for the agglomerations in question.
(2) a PDU applies to the territory within the transport perimeter (or its part).
(3) PDUs must be accompanied by an implementation plan which includes financing of investments and operating costs (a major advance relative to past practices);
(4) the authority for developing a PDU is given to AOs;
(5) PDUs must be subjected to public inquiry; they are adopted by the AO, following the approval by the member-communes; and
(6) the implementing authority remains with traditional agencies.

It should be noted that PDUs have been defined as studies, and no legal power has been assigned to them. The state has refrained, both on paper and in practice, from using its subsidies (notably through the development contracts for transit) to enforce integration. Finally, no relationship has been defined between PDUs and urban development plans.

No specific methodology has been decreed for the PDUs so far. The first generation of six cities which have developed PDUs, approached them in different ways, both with respect to political power-sharing arrangements and in technical matters. The stress on transit dominates all studies, however, as does the effort to revive the "forgotten" urban modes (walking, bicycling); they cover both the short and long term and propose actions ranging from tariff policies and transit network restructuring via safety campaigns to infrastructure development plans. It also appears that, apart from transport actions, the major output of these exercises relates to the modes of intercommunal cooperation and public participation.

WHAT LESSONS FOR DEVELOPING COUNTRIES?

The problems identified above notwithstanding, transit in France works very well: the services are satisfactory, the production side is reasonably efficient and, importantly, the system's dynamic nature allows it to evolve. What lessons could be drawn therefore for designing transit institutions in developing countries?

Five elements seem to this writer to hold keys to the French success in transit: the coherence of the system, the contracting approach, the role of competition, the decentralization of political power, and stability of the source of finance. Of the five, the first three offer a clear model for developing countries; as for the last two, the message is ambiguous.

Coherence

The French approach to transit is coherent because all important aspects of the system have been considered singly and in relation to each other. There exists an explicit policy, with basic principles expressed in laws which name all the key institutions, define their relationships, state political preferences and provide means for implementation (sources of finance and procedural tools). Subsequent decrees and advisory documents provide further details, while leaving substantial maneuvering space to actors, in line with the decentralization policy. It is worth repeating that the policy evolved out of a strong political consensus (for example, the VT tax was instituted by the right-of-center government, whereas the key principles were legislated later on by the political left-of-center).

It is this coherence which is lacking in developing countries: policy statements rarely exist, while the implicit policies are incomplete or contradictory, and relations between key actors are undefined. In several North African countries, for example, it is an established practice to use transit, particularly transit tariffs, as means of social policies (e.g., income redistribution), without the matching provision of compensation to transit enterprises; this practice has pushed once-profitable transit companies into bankruptcy. By contrast, French law defines transport as a social good, to be provided to certain users at reduced prices, and assumes that transit benefits are diffused beyond the actual transit users; from these premises follows the use of tariffs which do not cover costs, but also the principle of fair compensation and the principle of taxing secondary beneficiaries to provide means of creating equilibrium in transit accounts. Similarly, the principle of decentralization is matched by transferring the financial means to the local level.

Contracting Approach

The relationships among the principal actors take the form of contracts: between AOs and transit operators, between AOs and the state, between different AOs (e.g., between urban and regional AOs). Though actual contracts vary in degree of legality and need improvement in terms of incentives and balance in risk-bearing, they establish measurable goals (thus permitting evaluation and correction); clarify relationships and mutual responsibilities; and stress partnership and negotiation. Contrast this with a rather typical situation in developing countries where the relationships among the parties involved are murky, and the style is that of master (usually a technical ministry) to servant (a bus company).

Competition

For a service like urban public transport, which is held to provide an essential public good and thus may depart from market rules, the preservation and apparent well-being of private bus operators in France is a worthwhile achievement. Although the private sector is excluded from making capital ventures in transit (which would explain the probable oversupply of transit in some cities and an apparent low weight given to economic/financial aspects in some large-scale investment decisions), the competitiveness in the sphere of knowledge is very much alive and has resulted in tangible gains, both with respect to the technical dimension of transit operations and the relations between AOs and operators. It should be noted here that the many potential benefits from further involvement of private enterprise in transit are possible within the system structure as it exists now, requiring changes in parameters only (tariff policies, contract types); the system, except for the Paris region, seems to be evolving this direction (*22*).

As matters now stand, the role of French private enterprise in transit offers a model towards which publicly owned transit in many developing countries (notably in North and West Africa) could evolve with beneficial effects, without departing from the path of other social and political processes in these countries, as an outright divestiture might.

Decentralization

The redistribution of political power and fiscal means from central to local levels has been among the key elements contributing to the transit resurrection in France (*1*). Independent of arguing for decentralization as a way to increase democracy, in the field of transit in France it has permitted experimentation and variety: in technical matters, in tariff policies, in modes of organization and, importantly, in amounts of transit investment per capita. It may even have induced an element of financial responsibility, notably absent when urban wish lists are submitted to central governments for funding. In this respect, the parallels between decentralized decision-making and markets are quite strong. Nor should one disregard the benefits of matching local wishes to local resources, in those situations (however infrequent) where the politics of neglect of transit in well-to-do provincial cities are practiced by hard-strapped central governments.

The ambiguous aspect of decentralization lies in the capacity of local governments to muster the engineering, financial, and legal skills necessary to exercise their newly won powers to (inter alia) invest in and manage transit. Even in a highly developed country like France, it appears that local authorities, specifically AOs, have not possessed that capacity, and may not yet have it, except for some very large cities, though more than a decade has passed since AOs were created. They were certainly no match for the highly professionalized management of operating companies, with the result that many past investments were made without concern for the long-term impact of loans on local finance; forecasts of sources and applications of funds have only recently become evident in investment studies and research work (*13*). In this context, witness the recent founding of an association of AOs, an attempt to match vertical integration of operators (*23*).

If the situation described above has been the case in France, the absence of technical/financial skills in local government would be much more serious in developing countries, where even the central government may lack such expertise. It may well be better to build up central advisory units and regional offices of central institutions. Nor would it be possible to pursue decentralized decision-making in the urban transport sector in isolation from progress on the general front of political power-sharing.

Source of Finance

Adoption of the VT tax as a dedicated source of finance was probably the single most important element reviving French transit. It is illuminating that the financial commitment actually preceded policy development. The VT tax as a concept has some economic underpinning (diffusion of benefits beyond direct users of transit); it is a local source (thus providing some balance between local appetites and means), it is stable (based on salary mass), it is simple to collect, and it is flexible (rates can be increased depending on transit development strategy, or decreased or cancelled, or not instituted at all, according to political consensus). For all these reasons, the VT device should provide a useful model for developing countries.

Unfortunately, the VT tax as introduced in France is also a flawed tool. Its administrative simplicity is much stronger than its economic justification. Aside from traditional arguments against subsidies (not the least of which is that availability of large funds leads to overinvestment and overuse of transit, as it may have happened in France), the problems with the VT include the following:

(1) VT captures benefits from one class of potential beneficiaries (employers), but leaves others out of the equation, notably merchants employing fewer than 9 staff and real-estate owners (although the latter do pay the *taxe d'équipement*, part of which may flow into the transit investment funds);

(2) the amount collected is not related to the size of secondary benefits, hence the resulting investment budgets have been arbitrary; the availability of these funds may have led to progressively diminished direct user charges—farther and farther from economic reality;

(3) VT is inequitable, in that some employers benefit more from its proceeds and others less (or not at all, as used to justify several "VT strikes" in France): for example, merchants employing 9 or more staff do pay the VT, but their real benefits from transit relate not to their employees but to customers; and

(4) for small-scale enterprises, VT works against employment, which potentially constitutes its most serious flaw relative to developing countries, especially when it also includes threshold effects (concerning the size of enterprises).

The VT is therefore not recommended for "export" to developing countries in this particular French version. Alternative fiscal tools should be sought; they should be local but provide a better match between the tax, the classes of beneficiaries, and the size of benefits.

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