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> *Our troubled planet can no longer afford the luxury of pursuits*
> *confined to an ivory tower. Scholarship has to prove its worth,*
> *not on its own terms, but by service to the nation and the world.*
> *— Oscar Handlin*

Simulated Relationships between Highway Capacity, Transit Ridership, and Service Frequency

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Abstract

This article analyzes the relationships between highway capacity additions and transit patronage, both in the short and long run. A methodology using a model of schedule disutility is shown to provide a technique to account for transit service frequency. This technique, combined with a supply-side model of a highway corridor is used to evaluate the impact of transit headway changes and highway capacity, increases on total transit ridership, using a synthetic sample of commuters. Simulation results are used to evaluate the impact on travel times and utility of the two modes and the long-run degradation of transit service predicted by the Downs-Thomson paradox.

While the results do not show congestion as necessarily being worse than before capacity expansion, they do show that transit service frequency could be reduced significantly over time.

Introduction

The relative inconvenience of transit service compared to single-occupant vehicles (SOVs) is often cited as one of the primary reasons that transit ridership shares have been diminishing in recent years (U.S. Department of Transportation 1997). Much of this is due to new patterns of development that have decentralized jobs and other activities away from the urban core. This decentralization has resulted in difficulties in supplying transit services that provide coverage for the multitude of potential trips within a large metropolitan area.

Traditional transit services also run on fixed schedules with discrete time intervals.[1] This creates an additional source of inconvenience for users, especially if the fixed schedule deviates significantly from one's own desired schedule of activities. While frequent, more convenient service is difficult to provide in decentralized areas, service frequency has also been reduced in many urban areas and for trips to the central business district (CBD). It is well known that these service reductions will result in lower transit patronage (Voith 1991; Lago et al. 1981; Kain and Liu 1995). Morlok (1976) provided some of the first analyses demonstrating a relationship between transit frequency and passenger volumes.

Transit's level of inconvenience can be defined in two different ways: spatial inconvenience and temporal inconvenience. *Spatial inconvenience* of transit is a function of changing urban settlement patterns and is driven by the decentralization of urban areas. *Temporal inconvenience* refers to transit service that is relatively infrequent on existing routes, whether it serves suburban destinations or traditional routes to the CBD. Temporal inconvenience and its interaction with highway capacity is the focus of this article.

Changes in the attributes of SOV travel also affect transit ridership, especially in the long run. For example, increased road capacity has resulted in greater convenience and access for motor vehicles and has certainly contributed to reductions in transit patronage.

Highway capacity increases tend to result in unforeseen consequences. One of the paradoxes of transportation is the Downs-Thomson effect. This effect hypothesizes that highway capacity improvements may actually increase overall congestion and travel times (Arnott and Small 1994). One of the immediate effects of a highway capacity expansion, for a given congested corridor, is a shift from transit to private vehicle use by some travelers. The Downs-Thomson effect hypothesizes that this reduction in transit ridership will produce a reaction where either transit fares are raised to cover costs or service is reduced. This can occur for both privately operated systems that reduce service due to decreased revenue or for government-provided services that seek to minimize deficits for political reasons. Both reactions by the transit service provider tend to further diminish transit patronage and shift more people into private vehicles. In the worst-case scenario, transit service is completely eliminated and congestion within the corridor is worse than before the capacity expansion. Arnott and Small (1994) numerically show results where congestion can be worse after a highway capacity expansion. The procedure outlined in this article illustrates how reductions in service (and hence the convenience of transit) can result in this general effect, though the model used here does not show overall congestion increasing.

This topic has important implications for both the provision of transit services and how financing is efficiently provided. For example, Mohring (1972) suggested that one of the benefits of subsidizing transit service is to capture the external benefits of increased service frequency. Alternatively, Walters (1982) suggests that smaller vehicle sizes might be a more optimal solution that would enable more frequent service under competitive conditions. Voith (1991) makes a compelling argument for how increases in transit fares and service reductions (due to the need to reduce subsidies) actually lead to the need for increased subsidies as fewer people use the transit system. This article considers these effects by explicitly linking transit usage with changes in highway capacity, focusing on the relative scheduling convenience of the two modes.

The next section briefly discusses some issues and current practices in modeling transit and techniques used for modeling choice of travel time. This is followed by a discussion of the methodology used in this article as well as simulations that analyze alternative convenience levels and the Downs-Thomson effect. The conclusion provides some thoughts on interactions between transit and highway policy.

Current Modeling Practices

Most regional transportation planning in the United States utilizes some form of the four-step modeling process. For determining transit ridership, the key step is the mode choice model (usually a discrete choice logit model). These generally contain parameters related to cost, travel time (in and out of vehicle), and user demographics. There is normally no explicit attempt to account for the disutility due to scheduling effects. Out-of-vehicle travel times can serve as a proxy for some scheduling effects, though they may be more related to the reliability of the schedule. Generally, the coefficients on in-vehicle travel time are smaller than those on out-of-vehicle travel time. This probably implies some additional disutility associated with waiting, which is related to frequency of service.

When service frequency is high, waiting time may serve as a good proxy for scheduling effects. However, as Tisato (1998) points out, when service is less frequent, users will not arrive at transit stops randomly but will engage in "planned behavior" using information on transit departure times to better schedule their arrivals.

Recent research has attempted to model transfer penalties (Central Transportation Planning 1997), which could be interpreted as another form of inconvenience associated with transit. Transfer penalty coefficients were found to be significant and having a transfer was equated with about 15 to 20 minutes of travel time.

When transit service is unavailable between two zones within a region because it is very inconvenient, it will obviously not be modeled. Introduction of a new service between two previously unserved zones would be modeled using existing parameters estimated for the region or for a similar pair of zones.

Another branch of the literature is focused on approaches for optimizing transit system service parameters. These tend to assume fixed-passenger demand. The model developed by Spasovic and Schonfeld (1993) does not consider the impact of service frequency on overall passenger demand but does show how fixed-passenger demand leads to an optimal headway value. Banks (1990) develops a simulation model and concludes that optimal headways are minimally affected by assuming fixed demand. Kocur and Hendrickson (1982) consider variable demand in their optimization of transit costs and user benefits. These methods for optimizing transit service (by minimizing operator and user costs) do not allow explicit analysis of highway expansion policies on transit service, which is one of the objectives of this article.

Rigid transit schedules are related to the timing and scheduling flexibility associated with trips. Small (1982) estimated a model of scheduling choice that provides a foundation for building time-period choice models. The model includes parameters for the disutility associated with not arriving at the desired time. These parameters have been defined as schedule delay-early (SDE) and schedule delay-late (SDL). Bates (1996) provides an extensive review of other time-period choice modeling efforts, but concludes that Small's overall approach is the most attractive.

Few if any of these approaches have been applied in general practice and schedule disutility has not been applied to transit. Cambridge Systematics (1997) provides an assessment of the current practice of time-of-day choice modeling with a review of some innovative approaches taken by metropolitan planning organizations. With a few exceptions, none of the approaches reviewed are true attempts at multivariate modeling of travel time choice. They generally attempt to provide additional detail on fractions of peak and off-peak travel by facility and by mode for various trip types. A few innovative approaches do apply a peak-spreading algorithm. Most attempts are somewhat limited in their ability to analyze policy variables that affect scheduling utility and the choice of travel time in conjunction with choice of mode.

The procedure outlined in the next section applies Small's schedule disutility model to analyze shifts between transit and highway usage within a simple hypothetical travel corridor. The impacts of scheduling and highway capacity expansion policies and their relative impact on transit usage can then be evaluated.

Schedule Disutility and Transit Convenience

The methodology developed in this article builds on previous work on schedule disutility by Small (1982) and applies it to a system with a fixed headway. Small (1982) used data collected in the San Francisco Bay area to estimate a model of scheduling costs. The basic hypothesis is that commuters have a preferred time that they wish to arrive at work. They also want to minimize the time they spend traveling to work. It should generally be preferable to arrive before one's preferred time than to arrive later. A rational commuter will attempt to trade off between schedule delay and travel time to maximize utility. When there is no congested travel period, the trade-off is trivial and schedule delay is equal to zero. Under congested conditions, the commuter will choose a travel schedule that maximizes the utility between lengthier travel times and schedule delay. When applied to transit with a fixed headway, the commuter in some cases must choose to arrive either earlier or later than the preferred arrival time, if the transit schedule does not match the timing of the preferred arrival time.[2] Small (1982) postulated the following general model:

$$U = aT + \beta SDE + \gamma SDL + \theta D \tag{1}$$

where:

T = travel time,
SDE = schedule delay-early, and
SDL = schedule delay-late.

These are defined as:

$$SDE = \begin{cases} SD & \text{if } SD > 0, \\ 0 \text{ otherwise} \end{cases} \tag{2}$$

$$SDE = \begin{cases} -SD & \text{if } SD < 0, \\ 0 \text{ otherwise} \end{cases} \tag{3}$$

SD is total schedule delay or the difference between the actual and preferred arrival time. D is a dummy variable equal to 1 when $SDL > 0$ and would represent an additional fixed penalty for arriving even one minute late. Both SDE and SDL increase linearly as one arrives either earlier or later than the preferred arrival time.

Small (1982) estimated coefficients for this model using a disaggregate logit model. The coefficients derived were of the expected sign and relative magnitude; that is, $\beta > \alpha > \gamma$. Arriving early is less onerous than time spent traveling, which is less onerous than arriving late. All values were statistically significant. Small (1982) also analyzed other formulations using various demographic variables, whether the vehicle is a carpool or not, and models with a variable representing flexibility in workplace arrival times. The coefficients for the simple model (1) are:

$$U = -0.106T - 0.065SDE - 0.254SDL - 0.58D \tag{4}$$

This model can easily be applied to the case of a fixed-transit schedule. A commuter electing to use transit would generally have to choose some amount of early or late arrival even under uncongested conditions. This would simply be a function of how well the transit schedule matches the preferred work arrival time.

Relationships between Fixed Headways and Schedule Disutility

Assume that the scheduled arrival time of a transit vehicle is t_S. The transit schedule has a fixed headway between vehicles of H. Therefore, if the first transit vehicle arrives at scheduled time $t(1)$, the scheduled arrivals of all vehicles can be defined as:

$$\begin{aligned} t_1 &= t(1) \\ t_2 &= t(1) + H \\ t_3 &= t(1) + 2H \\ &\ldots\ldots \\ t_S &= t(1) + (S-1)H \end{aligned} \tag{5}$$

In practice, H may vary with time of day or even over the peak period. It is assumed here to be a fixed headway. It is also assumed that there is no uncertainty in length of headway so the problem of bunching of buses running with low headways in congested areas is ignored.

Schedule delay *(SD)* can be written as $SD = t_A - t_P$, where t_A is the actual arrival time and t_P is the preferred arrival time. The actual arrival time, (t_A) is determined by the choice of home departure time (t_h). *SDE* and *SDL* are redefined as functions of the preferred arrival time and the scheduled arrival, t_S which for transit is equal to t_A:

$$SDL = \begin{cases} t_S - t_p, \text{ if } t_S - t_p > 0 \\ 0 \text{ otherwise} \end{cases} \qquad (6)$$

$$SDE = \begin{cases} t_p - t_S, \text{ if } t_S - t_p < 0 \\ 0 \text{ otherwise} \end{cases} \qquad (7)$$

This allows a more general specification of Equation 1 to be defined where the utility (U) is a function of mode (M), home departure time (t_h), and preferred arrival time:

$$\begin{aligned} U(M, t_h, t_P) = {} & \alpha T(M, t_h) + \beta SDE(M, t_h, t_P) \\ & + \gamma SDL(M, t_h, t_P) + \theta D(M, t_h, t_P) \end{aligned} \qquad (8)$$

The volume of traffic (V) that the traveler expects to encounter determines the choice of home departure time. This also implies a set arrival time (t_A), which is a function of t_h.[3] For the transit mode, one can assume that travel time is independent of congestion levels if the vehicles travel on a separate guideway (e.g., a rail system).

The following section specifies a procedure for simulating the choice of both mode and departure time. This allows for the endogenization of actual vehicle travel times and provides a technique for measuring mode shifts for relative levels of temporal inconvenience.

Simulation with Endogenous Congestion

To simulate the impacts of various policies it is necessary to endogenize the impact of congestion on individual travelers. Vickrey (1969) originally specified a bottleneck model of congestion that Arnott et al. (1990) later combined with a schedule disutility model to determine the impact of congestion-tolling policies. Their approach is aggregate and does not provide detail on individual traveler reactions. Chu (1993) developed an approach that provides disaggregate detail by incorporating a discrete choice model of scheduling (more detailed than Small's) with a model of congestion technology as specified by the U.S. Bureau of Public Roads (1964) and used previously by Henderson (1981, 1985). Noland (1997), Small et al. (1995), and Noland (1999) extend the Chu model to account for reliability of travel time.

A nested logit formulation can be used to model the choice of mode and the choice of schedule (or departure time). This is superior to using a simple multinomial logit specification by eliminating the problem of independence of irrelevant alternatives (Ben-Akiva and Lerman 1985). For example, a multinomial specification would be sensitive to the number of choices of transit departure times available. All else equal, this would by itself result in fewer individuals using the transit mode since any elimination of a given choice results in proportional increases in the use of all other choices. A nested logit structure avoids this problem.

Nested logit models specify a logsum term that is the logarithm of the sum of the utility of a given nest. In this case, the nest represents the choice of departure times, hence the logsum (*LS*) is defined as:

$$LS_M = 1n \sum_{i=I}^{k} \exp[U_i(M)_1] \tag{9}$$

where: U_i is the utility function defined in Equation 8, for a given mode *(M)*, and the summation is over the *k* choices of departure time, t_h.

The logsum is then used in the upper nest of the logit model:

$$P(t_h, M) = \frac{eU_M + \delta_M LS_M}{\sum_M e^{U_M + \delta_M LS_M}} \tag{10}$$

This allows the generation of choice probabilities, $P(t_h, M)$, for each departure time and choice of mode. The coefficient for the logsum (δ_M) used in the simulations that follow was borrowed from the model developed by Chu (1993). The value of the logsum for vehicles is chosen to be 0.6842 and for transit is 0.2242. U_M is the utility of the chosen mode, which is limited to a single transit specific constant of -5.422 (again, derived from Chu 1993). Travel times for each mode are already contained in the lower nest and thus are already accounted for.

One could also use a more detailed mode choice specification that more fully describes the choice of transit. This could include alternative travel time parameters for the two modes. For simplicity, it is assumed that any additional disutility associated with transit is contained in the mode-specific constant.

The probabilistic choice demand model is applied using a synthetic sample of 5,000 individuals, each with a randomly assigned preferred arrival time, t_P. This is actually the time that an individual exits the highway facility. It is assumed that each commuter then faces some additional time to actually reach his or her desired location. The synthetic sample is drawn randomly from a normal distribution with mean preferred arrival time equal to 8:00 A.M. and standard deviation equal to 60 minutes. Sample enumeration of the synthetic sample allows the probabilistic demand model to forecast the probability of choosing specified departure times (for both the vehicle and transit mode), relative to the preferred arrival time for each individual.

To clearly measure the difference between a mode with fixed headways and one with maximum temporal convenience, the vehicle departure time choices are segmented into 121 1-minute choices of arrival times. Of these, 80 segments are for the choice of arriving between 1 minute and 80 minutes early. One choice is for arriving exactly at the preferred arrival time and 40 are for between 1 minute and 40 minutes late. The number of transit choices is determined by the specified headway for a given simulation. For example, if the headway is 5 minutes, then there will be 25 choices of scheduled transit service within the 121-minute time frame specified. A 10-minute headway would provide 13 choices (i.e., the number of transit choices = $120/H + 1$). Small's scheduling cost function (4) was estimated using 5-minute intervals over an hour for arrival times between 42.5 minutes early and 17.5 minutes late. Interpolation of choices for smaller time segments is not completely unrealistic. It is assumed that the choices apply over the 2-hour range specified (rather than Small's 1-hour range), however, simulations using a 61-minute interval produce essentially the same qualitative results with minor quantitative changes.

Sample enumeration of the choice probabilities for each travel time segment is calculated relative to the individual's randomly assigned preferred arrival time. This distribution of relative departure times is then allocated to specific 10-minute travel time slots. For example, if one individual has a preferred arrival time of 8:35 A.M., the probability that a schedule delay is -20 minutes is equivalent to the probability that the individual arrives in the time interval between 8:10 and 8:20 A.M. Traffic volumes are calculated for specified 10-minute time intervals.

Once traffic volumes have been calculated for specific time slots, one can determine the impact on travel times. To do this, the supply model cited by the U.S. Bureau of Public Roads (1964) is used:

$$T = l \left[T^0 + T^1 \left(\frac{V}{C} \right)^{\varepsilon} \right] \tag{11}$$

where:

T = travel time in minutes,
V = number of vehicles leaving the highway per hour,
C = capacity of the facility,
ε = elasticity parameter,
l = length of the facility (assumed to be equal to five miles), and
T^0 and T^1 = constants.

The values used here are the parameters from U.S. Bureau of Public Roads (1964): $\varepsilon = 4$ and $T^1/T^0 = 0.15$. $T^0 = 1.0$ minute/mile represents a free-flow speed of 60 miles per hour (mph). Traffic volume, V, is calculated at the point where the flow leaves the highway and is based on the expected work arrival time. This simulation methodology is adapted from Chu (1993).

The simulations modeled assume that transit is traveling on a fixed guideway and so would not be subject to congestion within the highway corridor. One could also simulate the model by placing transit vehicles (buses) on the highway and making adjustments to congested travel times including the buses in the traffic flow. This is not done in the simulations that follow so that transit speed is controlled as an exogenous variable.

New vehicle travel times are then fed back into the probabilistic choice model to determine a new distribution of departure times and mode choices. This process is continued until convergence conditions achieve a stable pattern of travel volumes over time. (Specifically, convergence is achieved when the sum of the absolute value of traffic volume differences between two iterations is less than one.) Simulation outputs include the congestion profile, the average travel delay, scheduling and mode choices, and the total cost (or utility).

Results of Simulations

This section discusses several simulations that were run to determine potential impacts on transit ridership. These include the ridership, travel time, and average utility effects of changes in transit headway and speed, and changes in highway capacity. Long-term responses of highway capacity are then evaluated by assuming transit operators will reduce service frequencies, as hypothesized by the Downs-Thomson effect.

Impact of Headways on Transit Ridership

A series of simulations were run to analyze the impact on demand for transit for varying transit headways, transit speed, and different highway capacity levels. It was found, not surprisingly, that as transit headways are increased (i.e., service frequency decreased), transit ridership volumes decline. Results are displayed in Figure 1 for a variety of capacity levels,[4] transit speeds, and different headways.

The results show that decreasing headways (i.e., increasing convenience) is an effective policy for increasing transit ridership. This is, of course, based on the parameters used in the schedule disutility function of Equation 4; other functional forms could give somewhat different results, although the general effects should be similar.

Highway construction or expansion projects are often packaged with transit expansion projects (ostensibly to address environmental and/or equity concerns). These results suggest that if transit headways are reduced within a corridor that has a highway capacity expansion, there could be some additional shifting to transit. For example, Figure 1 shows that reducing headways from 20 minutes to 10 minutes while increasing capacity from 150 to 300 vehicles (per 10-minute interval) results in an increase in transit share. As will be shown, the optimal headway may actually be higher, making it difficult to maintain a policy of increased service frequency.

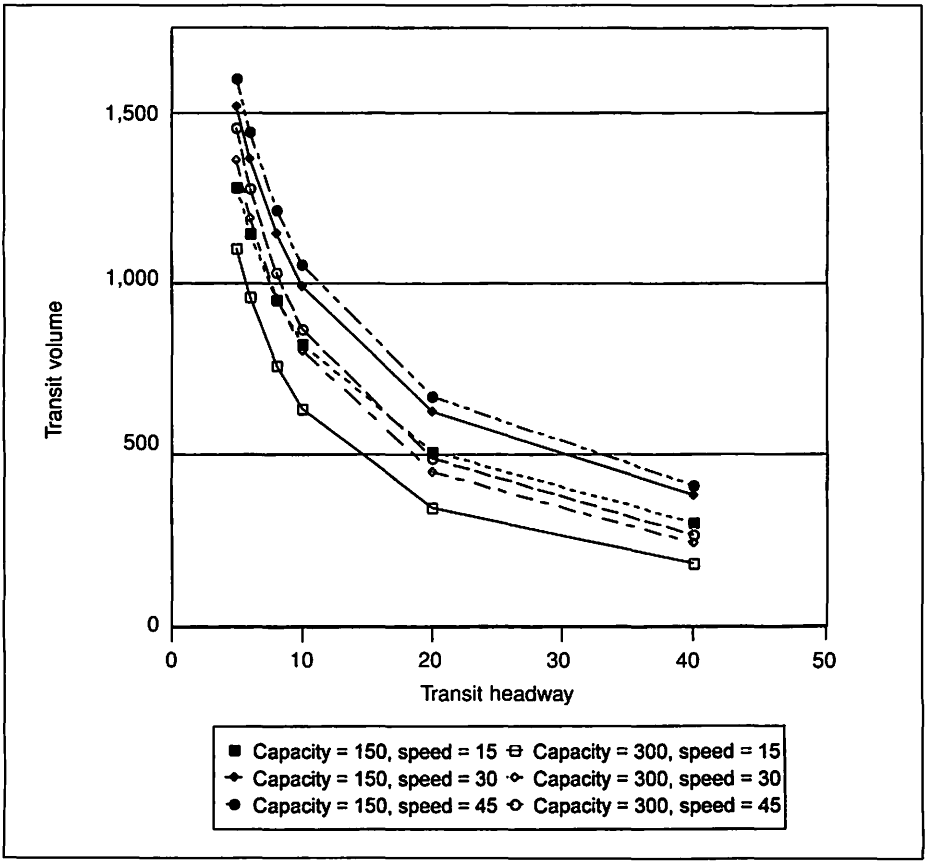

Figure 1. Transit volumes for differing levels of highway capacity, transit headway, and transit speed

The same basic relationship between headway and transit ridership is maintained for each of the simulations with different capacity and transit speed inputs. The output suggests a fairly simple relationship between transit headway and transit volumes. For this reason, a simple linear regression was analyzed relating transit volumes to headway, capacity, and transit travel times. These results are shown in Table 1 for a logarithmic transformation of the data. Not surprisingly, all estimated coefficients are statistically significant. The logarithmic transform allows one to read the parameter estimates as elasticity measures. Transit headway shows a relatively high elasticity value indicating that a 1 percent increase (decrease) in transit headways can reduce (increase) transit ridership by about 0.77 percent. Lago et al. (1981) measured headway elasticities that ranged from about -0.22 to -0.76 depending on various conditions. They found larger elasticities during off-peak periods when service levels were generally low and lower elasticities at the peak, probably reflecting the inability of those traveling at peak periods to reschedule their trips. The simulation modeled here makes no assumptions about individuals being transit captive, which would, of course, result in lower aggregate elasticity values.

Table 1
Regression of Transit Volume against Capacity, Headway, and Travel Time

Dependent Variable = Log (Transit Volume)	*Coefficient*	*Standard Error*
Constant	10.93	0.07
Log (Capacity)	-0.35	0.03
Log (Headway)	-0.77	0.01
Log (Transit travel time)	-0.24	0.02
R^2	.99	
N	72	

Another recent study by Kain and Liu (1995) estimated elasticities of revenue miles. Their estimate represents a measure of service quality similar, but different, than a headway measure. Their elasticities ranged from about 0.7 to as high as 1.0. While the comparison is not strictly comparable to headway results, it falls within the general range of the results above.

Voith (1991) measured short- and long-run elasticities using the number of peak and off-peak trains as a proxy for service quality. His elasticity values for peak-hour trains are 0.14 in the short run and 0.36 in the long run. For off-peak trains, the values are higher: 0.74 in the short run and 1.89 in the long run. Those traveling at peak may be more constrained in their choice of alternatives, hence they have lower elasticity values than those traveling during off-peak periods.

The analysis shows a clear relationship between transit usage and the frequency of transit service (i.e., headways). Long-run impacts and the Downs-Thomson paradox are analyzed and discussed below.

Variations in Travel Times and Utility

Average utility values, travel times, and modal shares for vehicle users and for transit users can be calculated using simulation results. This information provides some insight into how capacity changes affect these outcomes.

Average transit travel times were simulated at four levels (15, 30, 45, and 60 mph) while free-flow highway travel times were assumed to be 60 mph. Simulations with 60 mph transit travel speeds provide consistently faster peak travel times for transit vehicles than for highway vehicles.[5] Table 2 shows that the immediate impact of a capacity expansion is to reduce both transit usage and both average and "peak" vehicle travel times in all cases.[6] Potential longer term travel time impacts are discussed below.

Of more interest than travel times is the impact on average total utility. Separate components of utility, such as travel time utility, schedule delay utility, and lateness penalty utilities, are calculated using the parameters of Equation 4. These results are shown in Table 3. Average utility per traveler increases as capacity is increased. This is even true for the case where transit speeds exceed vehicle speeds. The only component of utility for vehicle users that significantly changes is the utility associated with travel time. The schedule delay utilities do not vary with capacity or speed of transit service. The average utility for transit users also does not vary.[7]

As transit headways are increased, the average utility for all travelers is expected to decrease as shown in Table 4. One would expect that this is pri-

Table 2
Travel Time (simulations for headway = 5 minutes)

Capacity (volume/10-minute interval)	*Transit Speed (mph)*	*Number of Vehicles*	*Number of Transit Users*	*Average Travel Time (minutes)*	*Average Vehicle Travel Time (minutes)*	*Average Transit Travel Time (minutes)*	*Average Peak Travel Time (minutes)*	*Average Peak Vehicle Travel Time (minutes)*
150	15	3,716.17	1,283.76	10.133	6.724	20.00	10.655	7.415
225	15	3,861.69	1,138.24	8.774	5.466	20.00	8.815	5.653
300	15	3,893.97	1,105.96	8.442	5.159	20.00	8.358	5.223
150	30	3,481.93	1,518.01	7.467	6.363	10.00	7.844	6.912
225	30	3,610.34	1,389.59	6.649	5.359	10.00	6.712	5.503
300	30	3,638.70	1,361.23	6.450	5.122	10.00	6.434	5.170
150	45	3,397.97	1,601.96	6.383	6.249	6.67	6.724	6.751
225	45	3,519.39	1,480.55	5.722	5.325	6.67	5.803	5.456
300	45	3,546.06	1,453.87	5.562	5.110	6.67	5.577	5.154
150	60	3,354.91	1,645.03	5.800	6.193	5.00	6.128	6.672
225	60	3,472.63	1,527.31	5.214	5.309	5.00	5.305	5.433
300	60	3,498.41	1,501.53	5.073	5.104	5.00	5.104	5.146

Table 3
Average Utility of Travel (simulations for headway = 5 minutes)

Capacity (volume/10-minute interval)	*Transit Speed (mph)*	*Average Utility*	*Average Utility for Vehicle Users*	*Average Utility for Transit Users*	*Average SDE for Vehicle Users*	*Average SDE for Transit Users*	*Average SDL for Vehicle Users*	*Average SDL for Transit Users*	*Average Lateness Penalty for Vehicle Users*	*Average Lateness Penalty for Transit Users*	*Time Utility for Vehicle Users*	*Time Utility for Transit Users*
150	15	-1.524	0.068	-6.130	-1.1137	-1.7072	-0.2177	-0.7373	-0.0795	-0.1248	-2.7723	-4.4177
225	15	-1.275	0.157	-6.133	-1.1083	-1.7073	-0.2166	-0.7374	-0.0793	-0.1248	-2.6453	-4.4262
300	15	-1.217	0.179	-6.133	-1.1071	-1.7073	-0.2163	-0.7374	-0.0793	-0.1248	-2.6143	-4.4279
150	30	-1.717	0.102	-5.890	-1.1120	-1.7071	-0.2173	-0.7373	-0.0794	-0.1248	-2.7231	-3.3456
225	30	-1.513	0.173	-5.891	-1.1079	-1.7071	-0.2165	-0.7373	-0.0793	-0.1248	-2.6224	-3.3525
300	30	-1.466	0.190	-5.892	-1.1070	-1.7071	-0.2163	-0.7373	-0.0793	-0.1248	-2.5985	-3.3539
150	45	-1.784	0.113	-5.810	-1.1115	-1.7071	-0.2172	-0.7373	-0.0794	-0.1248	-2.7070	-2.9880
225	45	-1.595	0.178	-5.811	-1.1077	-1.7071	-0.2165	-0.7373	-0.0793	-0.1248	-2.6146	-2.9944
300	45	-1.553	0.193	-5.811	-1.1069	-1.7070	-0.2163	-0.7373	-0.0793	-0.1248	-2.5930	-2.9957
150	60	-1.818	0.119	-5.770	-1.1112	-1.7071	-0.2172	-0.7373	-0.0794	-0.1248	-2.6991	-2.8092
225	60	-1.637	0.181	-5.771	-1.1077	-1.7070	-0.2165	-0.7373	-0.0793	-0.1248	-2.6107	-2.8153
300	60	-1.596	0.195	-5.771	-1.1069	-1.7070	-0.2163	-0.7373	-0.0793	-0.1248	-2.5902	-2.8165

Table 4
Average Utility of Travel for Different Transit Headways and Highway Capacity (speed = 30 mph)

Transit Headway	*Capacity*	*Average Utility*	*Average Utility for Vehicle Users*	*Average Utility for Transit Users*	*Average SDE for Vehicle Users*	*Average SDE for Transit Users*	*Average SDL for Vehicle Users*	*Average SDL for Transit Users*	*Average Lateness Penalty for Vehicle Users*	*Average Lateness Penalty for Transit Users*	*Time Utility for Vehicle Users*	*Time Utility for Transit Users*
5	150	-1.717	0.102	-5.890	-1.1120	-1.7071	-0.2173	-0.7373	-0.0794	-0.1248	-2.7231	-3.3456
10	150	-1.190	0.018	-6.052	-1.1164	-1.7947	-0.2182	-0.7209	-0.0795	-0.1222	-2.8426	-3.3720
20	150	-0.830	-0.059	-6.217	-1.1213	-1.9598	-0.2192	-0.6918	-0.0797	-0.1180	-2.9520	-3.3917
40	150	-0.598	-0.122	-6.391	-1.1259	-2.2465	-0.2201	-0.6484	-0.0798	-0.1099	-3.0407	-3.4039
5	300	-1.466	0.190	-5.892	-1.1070	-1.7071	-0.2163	-0.7373	-0.0793	-0.1248	-2.5985	-3.3539
10	300	-0.834	0.165	-6.054	-1.1074	-1.7945	-0.2164	-0.7209	-0.0793	-0.1222	-2.6344	-3.3830
20	300	-0.423	0.148	-6.219	-1.1077	-1.9597	-0.2165	-0.6920	-0.0793	-0.1179	-2.6597	-3.4036
40	300	-0.181	0.137	-6.395	-1.1080	-2.2457	-0.2165	-0.6488	-0.0793	-0.1095	-2.6756	-3.4154

marily due to the shift to vehicle travel resulting in some increase in congestion and/or schedule delay. Most of this decrease in utility falls on vehicle users and is driven mainly by increases in travel time (or decreases in travel time utility for vehicles). As transit headways increase to 40 minutes, average utility for transit users also decreases. This effect is driven by reductions in the components of utility associated with schedule delay with minor variation due to the time component.[8]

When capacity is increased, average utility for all travelers does improve. The change is primarily due to a shift from transit use. Average utility for transit users stays constant as capacity increases (although the total number of transit users is less). Interestingly, for both vehicle and transit users, the components of scheduling utility do not vary significantly. This shift is driven by vehicle travel time reductions associated with capacity increases, which, as will be seen, are overestimated when long-term responses are not considered.

Long-Term Responses: The Downs-Thomson Paradox

Increases in highway capacity have long been known to attract additional traffic (Downs 1962). The immediate impact occurs due to rescheduling and route shifting but other impacts include the generation of previously avoided trips and shifts from transit to motor vehicles. The simulations clearly demonstrate this latter effect in combination with rescheduling of trips toward the peak.

One of the more perverse effects of adding highway capacity is the Downs-Thomson paradox (Arnott and Small 1994). This paradox describes how a highway capacity increase could actually increase total congestion. If the capacity increase occurs in a corridor served by transit, it could result in a reduction in transit service frequency shifting additional people to motor vehicles. In some cases this could increase total travel time within the corridor or at least diminish the originally planned benefits of expanding the facility.

The simulation results are used to estimate how a capacity expansion can lead to long-term degradation in transit service. Assume first that there is an initial increase in highway capacity. This results in a short-run decrease in transit ridership (as discussed previously and demonstrated by the simulations).

The Downs-Thomson paradox can then come into play. The reduction in transit ridership triggers either an increase in transit fares (to cover lost revenue) or a decrease in service frequency (to reduce costs). If transit ridership is reduced, for example by 10 percent, it is assumed that service frequency is reduced by 10 percent (headway increased by 10%). This leads to a further reduction in transit usage. The regression displayed in Table 1 is used to calculate this iterative effect until convergence is achieved.[9] Results are shown in Table 5.

Table 5
Changes in Headway due to Highway Capacity Increases

New Capacity (volume/10-minute interval)	*Optimal Headway (minutes)*
160	5.48
175	6.15
200	7.11
225	7.93
300	9.82
450	12.24
600	13.78

Note: Original capacity is 150 vehicles/10-minute interval. Original headway is 5 minutes.

Table 5 describes results assuming that headways are initially equal to 5 minutes and capacity is equal to 150 vehicles per 10-minute interval. If capacity is increased to 225 vehicles per 10-minute interval, then a new equilibrium will be established such that the optimal headway is now 7.93 minutes. An increase in capacity to 600 vehicles per 10-minute interval results in a new equilibrium at an optimal headway of 13.78 minutes. These results are not dependent on transit speed, though different transit speeds result in different volumes of transit ridership. Figure 2 graphs the optimal transit headway versus the increase in highway capacity. Initially, relative increases in optimal headway are rather large, diminishing as larger increases in capacity occur. This suggests that small increases in highway capacity can potentially result in

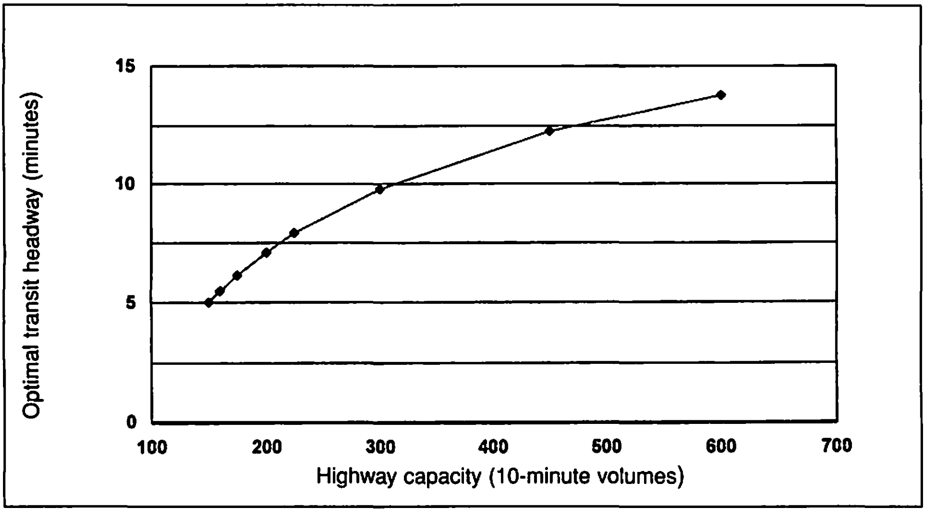

Figure 2. Optimal transit headway versus highway capacity

pressures for relatively large reductions in transit service frequency to obtain the optimal level of service. Figure 3 shows the difference in transit ridership between an initial equilibrium and a full equilibrium effect when transit headways are adjusted to a new optimal level. The effect is quite substantial and very large as capacity levels increase.

This clearly shows that long-term reductions in transit ridership can be induced by increases in highway capacity without any change in transit fares. The Downs-Thomson paradox implies that overall congestion levels could be worse than before the capacity expansion. In the examples analyzed here, this does not seem to be the case. The capacity increase still results in reductions in travel time even after the reduction in transit frequency. For example, the optimal headway after expanding highway capacity to 300 vehicles per 10-minute interval is 9.82 minutes (Table 5). Simulated average vehicle times for a capacity of 300 and a headway of 10 minutes are 5.25 minutes, still less than the average vehicle travel time of over 6 minutes (Table 2). Utility values are also still greater even after a new optimal headway is established.

Mohring (1972) developed a model to determine optimal urban bus subsidies. As part of that model, Mohring asserts and estimates a relationship between optimal service frequencies and demand for transit use. This is for-

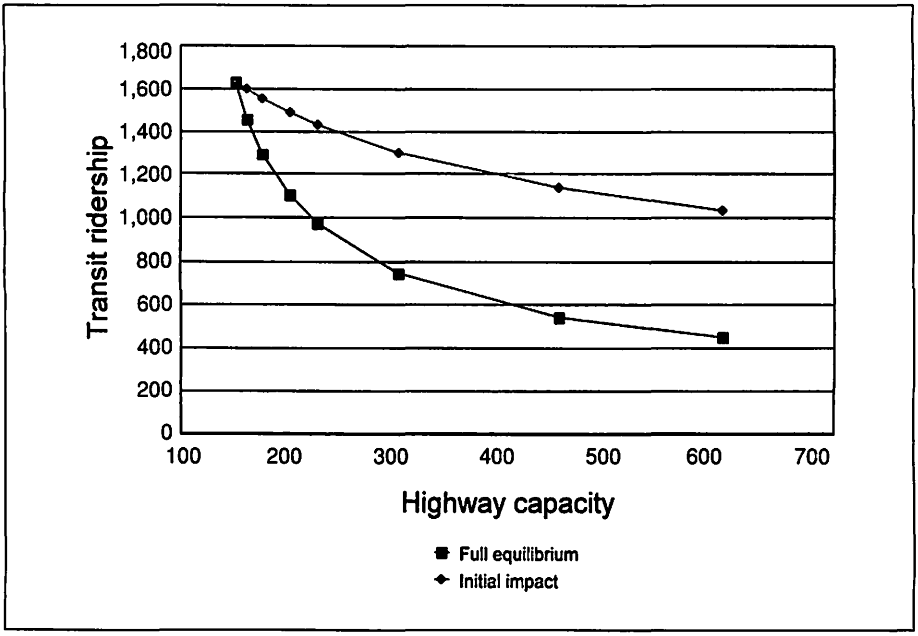

Figure 3. Full equilibrium and initial impact of highway capacity increase on transit ridership

mulated as a "square root rule," where the optimal frequency is equivalent to the square root of bus usage. The results here show the same general relationship. Figure 4 graphs optimal hourly service frequency (60 minutes/optimal headway) versus the square root of optimal transit ridership (as estimated after correcting for the Downs-Thomson effect). In general, the relationship is linear indicating a correspondence between these calculations and the results derived by Mohring (1972).

One caveat to the simulations is that the sample of 5,000 individuals used is static. One would expect capacity increases to induce generation of some new trips (other than just shifts from transit). Also, over time one would expect exogenous growth in travel due to population growth. If transit frequencies do not increase in proportion (due perhaps to a political decision to provide less support to transit since it is carrying fewer people), then again overall travel times could be reduced compared to not adding additional highway capacity.

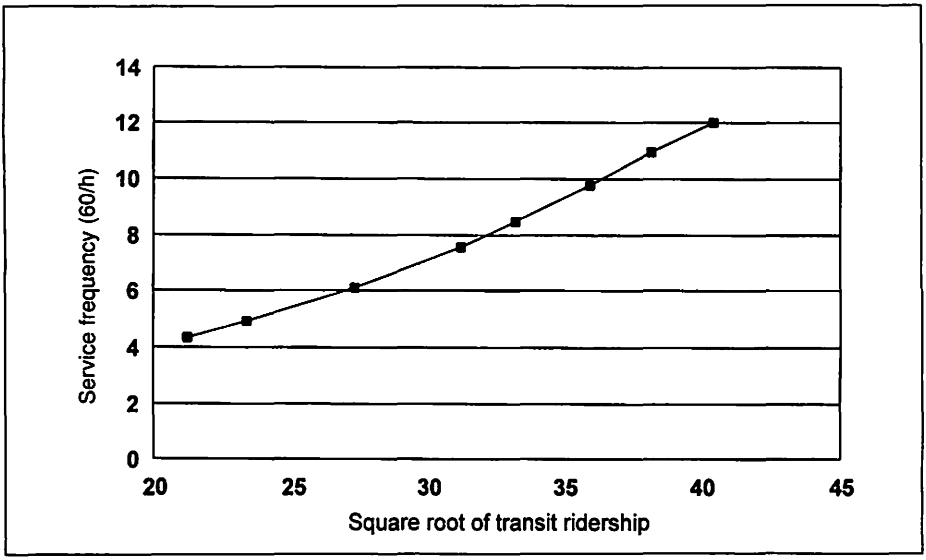

Figure 4. Optimal service frequency versus square root of transit ridership

Conclusions

The analysis presented here shows that transit service reductions clearly result in reduced transit ridership. The simulations do this using only scheduling costs as defined in Equation 4. The methodology also demonstrates that highway capacity increases result in both an immediate reduction in transit use and potentially a long-run reduction based on the behavioral assumptions of the Downs-Thomson paradox. While the simulations analyzed here do not show highway congestion to be worse than before the capacity expansion, other input assumptions could result in this occurring.

The results presented here should not be interpreted as definitive. The models used were relatively simple and many other factors could be attributed to modal shifts. However, the schedule disutility formulation used is relatively robust, and while the magnitude of the relative impacts may not be exact, the overall directions of the various changes due to headway increases or capacity changes are intuitively correct.

These types of impacts certainly question whether increasing road capacity is a solution for congested corridors or regions. Increasing service frequency of transit (and/or reducing fares) could, in some cases, reduce vehicle travel. Despite the innovations of the U.S. Intermodal Surface Transportation Efficiency Act of 1991 and its successor, the Transportation Equity Act of 1998, federal funding does not contribute major funding to transit operations. Most funding is restricted to capital improvements. Better uses of "transit" money may be to increase service frequency (and/or reduce fares). Decision-makers at the state and federal levels should evaluate the ability of increased transit service (on existing routes) as a means of meeting both transportation and environmental goals.

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Endnotes

1. Other transit services that are not considered traditional include jitneys and demand-activated services (Klein et al. 1997; Cervero 1996).
2. Or as is discussed in the simulations, the commuter will choose a mode other than transit that better matches their preferred schedule.
3. This model assumes no stochasticity in travel times from day to day. Noland and Small (1995) developed a model of uncertain travel times.
4. Capacity levels shown are based on 10-minute travel time intervals and were selected to provide realistic levels of congestion for a simulation using only 5,000 travelers. This was done primarily to shorten computational time.
5. The simulations are only assuming travel within a specified five-mile corridor. In any specific situation, one would expect additional door-to-door travel times to be associated with each mode.
6. The "peak" here is defined as trips arriving between 7:00 A.M. and 9:00 A.M.
7. Some minor variation in the average utilities is due, most likely, to rounding errors in the simulation. The values are certainly not significant to three decimal places.

8. While travel time for transit is modeled as constant, the average utility varies slightly due to changes in the logsum associated with alternative headways.
9. The iteration could also be calculated using the overall simulation approach, but this is computationally difficult due to the integer headway values used in the simulations.

References

Arnott, R., A. de Palma, and R. Lindsey. 1990. Economics of a bottleneck. *Journal of Urban Economics* 27: 111–130.

Arnott, Richard, and Kenneth Small. 1994. The economics of traffic congestion. *American Scientist* 82: 446–455.

Banks, James H. 1990. Optimal headways for multiroute transit systems. *Journal of Advanced Transportation* 24: 127–155.

Bates, J. J. 1996. *Time period choice modeling: A preliminary review*, Final report for the U.K. Department of Transport–HETA Division.

Ben-Akiva, M., and S. R. Lerman. 1985. *Discrete choice analysis: Theory and application to travel demand.* Cambridge, Massachusetts: The MIT Press.

Cambridge Systematics, Inc. 1997. *Time-of-day modeling procedures, state-of-the-practice, state-of-the-art.* Washington, DC: Travel Model Improvement Program, U.S. Department of Transportation and U.S. Environmental Protection Agency.

Central Transportation Planning. 1997. *Transfer penalties in urban mode choice modeling.* Washington, DC: Travel Model Improvement Program, U.S. Department of Transportation and U.S. Environmental Protection Agency.

Cervero, Robert. 1996. *Commercial paratransit in the United States: Part I: Service options, markets, and performance.* Berkeley: Institute of Urban and Regional Development, University of California.

Chu, X. 1993. Trip scheduling and economic analysis of transportation policies, Ph.D. dissertation, University of California, Irvine, Department of Economics.

Downs, A. 1962. The law of peak-hour expressway congestion. *Traffic Quarterly* 16: 393–409.

Henderson, J. V. 1981. The economics of staggered work hours. *Journal of Urban Economics* 9: 349–364.

Henderson, J. V. 1985. Economic theory and the cities, 2nd ed. New York: Academic Press.

Kain, John F., and Zhi Liu. 1995. *Secrets of success: How Houston and San Diego transit providers achieved large increases in transit ridership.* Federal Transit Administration, Office of Planning.

Klein, Daniel B., Adrian T. Moore, and Binyam Reja. 1997. *Curb rights: A foundation for free enterprise in urban transit.* Washington, DC: Brookings Institution Press.

Kocur, George, and Chris Hendrickson. 1982. Design of local bus service with demand equilibriation. *Transportation Science* 16: 149–170.

Lago, Armando M., Patrick D. Mayworm, and J. Matthew McEnroe. 1981. Ridership response to changes in transit service. *Transportation Research Record 818,*13–19.

Mohring, Herbert. 1972. Optimization and scale economies in urban bus transportation. *American Economic Review* 62: 591–604.

Morlok, E. K., 1976. Supply functions for public transit: Initial concepts and models. *Traffic equilibrium methods: Economic and mathematical Systems.* M. A. Florian, ed. Springer-Verlag, 322–367.

Noland, R. B. 1997. Commuter responses to travel time uncertainty under congested conditions: Expected costs and the provision of information. *Journal of Urban Economics* 41: 377–406.

Noland, R. B. 1999. Information in a two-route network with recurrent and nonrecurrent congestion. In *Behavioral and network impacts of driver information systems.* Richard Emmerink and Peter Nijkamp, eds. Aldershot, UK: Ashgate/Avebury.

Noland, Robert B., and Kenneth A. Small. 1995. Travel time uncertainty, departure time choice, and the cost of morning commutes. *Transportation Research Record 1493*, 150–158.

Small, Kenneth A. 1982. The scheduling of consumer activities: Worktrips. *American Economic Review* 72(3): 467–479.

Small, Kenneth A., Robert B. Noland, and Pia Koskenoja. 1995. *Socioeconomic attributes and impacts of travel reliability: A stated preference approach.* California PATH Research Report, UCB-ITS-PRR-95-36.

Spasovic, Lazar N., and Paul M. Schonfeld. 1993. Method for optimizing transit service coverage. *Transportation Research Record 1402*, 28–39.

Tisato, Peter. 1998. Service unreliability and bus subsidy. *Transportation Research A* 32: 423–436.

U.S. Bureau of Public Roads. 1964. *Traffic assignment manual*. Washington, DC.

U.S. Department of Transportation. 1997. *Transportation statistics annual report 1997*. BTS97-S-01. Washington, DC: Bureau of Transportation Statistics.

Vickrey, W. S. 1969. Congestion theory and transport investment. *American Economic Review, Papers and Proceedings* 59: 251–260.

Voith, R. 1991. The long-run elasticity of demand for commuter rail transportation. *Journal of Urban Economics* 30: 360–372.

Walters, A. A. 1982. Externalities in urban buses. *Journal of Urban Economics* 11: 60–72.

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A Systems Model for Evaluating Transit Performance

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Abstract

The purpose of this study was to illustrate how a systems modeling approach to transit performance measurement can be used to integrate the issues of service quality, efficiency, and effectiveness. The mathematical formulation of the systems model developed in this article was used to construct a single transit performance metric that can be used by elected officials, transit system personnel, taxpayers, and other decision-makers to compare similar transit systems. In this study, the systems model was applied to a set of small transit systems operating in the United States. Results revealed that fewer than one-fourth of these systems were efficiently using labor, fuels, materials, and capital to provide quality transit service.

Introduction

During the past decade, public transit systems in the United States have faced mounting public pressure to decrease operating costs, improve productivity, reduce subsidies, and increase ridership, while ensuring a level of service that is acceptable to their riders (Briddell and Arden 1998; Obeng and Ugboro 1996; Takyi, Obeng, and Ugboro 1993; Talley 1988). In addition, the growing emphasis on Total Quality Management (TQM) in public transit management has resulted in a need for greater public awareness of and involvement in transportation planning issues. One starting point for increased public awareness involves better understanding of transit operating costs (Cunningham, Young, and Lee, 1997).

In particular, an individual system's effectiveness in translating these costs into actual transit services may be of interest to the public, especially if this effectiveness can be characterized as being higher or lower than for comparable transit systems. Consequently, a variety of stakeholders in an individual public transit system—local planners, politicians, media, and transit system personnel—may find a summary metric of transit performance useful in describing to the public how the local system compares with other transit systems. Of course, elected officials and transit personnel may also use such a summary measure as part of the transit management process.

Currently, there is considerable disagreement within the literature about the best way to measure overall transit system performance, especially given the growing emphasis on service quality. Innovative approaches to assessing transit performance are clearly required. In response to this need, this article proposes a systems approach to measuring transit performance that integrates the issues of service quality, efficiency, and effectiveness. An example of a systems model for transit performance evaluation is presented. A mathematical model that operationalizes this illustrative model is formulated and applied to actual performance data for a set of peer transit systems. A single performance measure generated by the model is then used to classify peer transit systems as either relatively efficient or inefficient producers of multiple service outputs.

Literature Review

During the 1990s, a number of researchers cited the shortcomings of single performance ratios that have traditionally been used to evaluate public transit systems (Pullen 1993; Obeng, Assar, and Benjamin 1992; Fielding 1992). These single performance indicators are generally classified as either efficiency or effectiveness metrics (Pullen 1993; Chu, Fielding, and Lamar 1992; Talley 1988; Gleason and Barnum 1982; Fielding 1987; Talley and Anderson

1981; Silcock 1981; Stokes 1979; Hatry 1980). Efficiency indicators measure the extent to which resources are used economically (Stuart 1997; Gleason and Barnum 1982), whereas effectiveness measures for public transit systems typically indicate "how well the [transit] services produced meet the objectives set for them" (Pullen 1993, p. 248). To a large extent, transit objectives have traditionally involved transit usage goals such as increasing the number of passengers per vehicle hour (Gleason and Barnum 1982; Stokes 1979; Fielding, Glauthier, and Lave 1978; Talley 1988). However, in recent years, quality of service has emerged as an important type of effectiveness indicator (Cunningham, Young, and Lee 1997; Talley 1988; Fielding 1992; Pullen 1993). While "there is no definitive set of quality service indicators" (Pullen 1993, p. 249), frequently cited quality measures include reliability of service, safety, comfort, and accessibility (Pullen 1993; Fielding 1992).

Since overall public transit system performance encompasses multiple dimensions, a number of researchers have called for the development of a group of performance metrics for comparing peer systems (Chu, Fielding, and Lamar 1992). While it may be appealing to use multiple measures for public transit performance, reliance on multiple metrics may pose difficulties. Obeng, Assar, and Benjamin (1992) illustrated that the use of multiple performance indicators may yield conflicting results and suggested that a possible remedy for this problem may lie in the development of a single metric "that best describes the overall performance of transit systems." In a similar vein, Chu, Fielding, and Lamar (1992, p. 224) argued that performance analysis for public transit systems must "progress from multiple measures and partial comparisons to more robust indicators of performance." Finally, some of the stakeholders in a local transit system—including elected officials, the media, and the taxpayers themselves—may actually prefer a single metric that summarizes the relative overall performance of a local transit system.

A single overall measure of transit performance possesses several characteristics that may be attractive to these stakeholders. The first trait is simplicity. This characteristic is desirable because the public may have a difficult time judging overall performance when confronted by a lengthy series of individual performance ratios, particularly if some of these ratios trend in opposite directions. Thus, an overall performance metric can help to remove ambiguity and confusion caused by overwhelming stakeholders with many small pieces of information. A second characteristic is that a relative overall measure facilitates comparisons between an individual system and peer systems. It is not difficult for most stakeholders to understand that a local system with a score of 0.45 or 45 percent (out of a maximum rating of 1.0 or 100%) is somehow not performing as well as a neighboring system having a rating of 0.97. A third characteristic is that if the overall metric is carefully constructed so that it represents the output of an appropriate and mathematically rigorous methodology, the methodology itself may provide additional insights on individual system performance. Such a methodology thus possesses explanatory power, which may help local decision-makers and elected officials interpret the rating results for the public.

Since a comprehensive performance metric, "like virtually all performance measures, must confront the possibility that the quality of transit output may improve" (Talvitie and Obeng 1991, p. 171), it must capture service quality variables as well as efficiency and effectiveness data. One way of integrating the issues of service quality, efficiency, and effectiveness is to apply a systems approach to transit performance measurement (Fielding 1987; Gleason and Barnum 1982; Abbas and Bell 1994). General systems theory "characterizes an organization as a unified system of interrelated parts" and a "systems approach filters reality so that interactions and interdependencies can be understood" (Fielding 1987, p. 2). An example of a systems model for transit performance evaluation is discussed in the following section. The theoretical version of this systems model is presented first; then, a mathematical formulation of the model is used to calculate a single overall performance metric for individual transit systems.

A Systems Model for Transit Performance

A systems approach to transit performance reflects the fact that "transit organizations are resource-dependent open systems" (Fielding 1987, p. 3).

Thus, the systems approach not only depicts a relationship between resource inputs and service produced, it also indicates how well resources are used to meet passenger needs (Fielding 1987, p. 8). Therefore, if a single metric for overall system performance is to be developed from a systems model, that metric must reflect the efficiency, effectiveness, and quality of service of the transit system being evaluated. Figure 1 presents an example of a systems model that provides such a performance metric. In this illustrative model, multiple resource inputs are used to produce multiple service outputs.

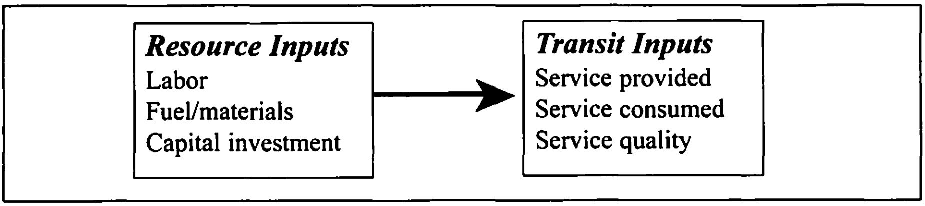

Figure 1. Systems model for transit services

The inputs of labor, fuel/materials, and capital investment are modeled as inputs because they are considered key resources in most public transit operations in the United States (Briddell and Arden 1998; Obeng, Assar, and Benjamin 1992; Fielding 1987; Chu, Fielding, and Lamar 1992; Nolan 1996). The outputs shown in Figure 1 are considered simultaneously because resource utilization not only leads to the provision of transit services, but also influences the extent to which services are consumed and how passengers perceive the quality of transit service delivery. For example, a bus driver provides transit service by operating a vehicle; however, he or she influences rider perceptions (and potential future service consumption) via driving skills (or lack thereof) and courtesy, helpfulness, and attention to passengers (Sulek, Lind, and Marucheck 1995). Similarly, maintenance labor can affect service availability (i.e., service provision) as well as service safety, consistency, and passenger comfort, which are issues related to service quality.

Table 1 lists the measures used to operationalize the input and output variables depicted in Figure 1. All of these measures are reported in the *National Transit Database* (formerly, *Section 15 National Urban Mass Transportation*

Table 1
Model Operationalization

Model Variable	*Operationalization*
<u>Resource Inputs</u>	
Labor	Total annual labor costs
Fuel/materials	Costs of maintenance materials, fuel, and other inventory
Capital investment	Fleet size
<u>Transit Outputs</u>	
Service provided	Annual revenue capacity miles
Service consumed	Unlinked passenger trips
Service quality	Annual vehicle miles/annual number of collision accidents

The source of this data is the Section 15 data for 1991, available from the U.S. Department of Transportation.

Statistics), compiled yearly by the U.S. Department of Transportation. The labor variable is represented by total annual labor costs. Labor costs tend to overshadow all other transit operating costs and comprise almost 75 percent of the total cost of producing public transit services, making total labor costs a critical component of a systems model for transit performance (Briddell and Arden 1998; Fielding 1987; Chu, Fielding, and Lamar 1992). The second variable, fuel/materials, is represented by the sum of annual costs for maintenance materials, fuels, and other inventory. The capital investment variable is measured by number of vehicles (or fleet size); the use of fleet size as a surrogate for capital investment in public transit operations is standard practice in the transit literature (Fielding 1987; Obeng, Assar, and Benjamin 1992; Nolan 1996).

Three measures are used in Table 1 to operationalize the model's output variables. The service-provided variable is measured by *annual revenue capacity miles*, which is defined as "actual revenue vehicle miles multiplied by the average passenger capacity of the active revenue vehicles in the fleet." Average passenger capacity is calculated by "averaging the sum of the seated capacity and standing capacity of all active vehicles in the fleet" (*Glossary of Transit Terms* 1990, p. 12). Annual revenue capacity miles is viewed in the transit literature as an appropriate metric for service provided because it measures the service capacity produced, "expressed in nonmonetary terms" (Fielding 1987, p. 64). The second output variable, service consumed, is measured by the frequently used effectiveness metric *unlinked passenger trips* (see Chu, Fielding, and Lamar 1992). Fielding (1987, p. 76) notes that "unlinked passenger trips are the most reliable statistic from the Section 15 data and are preferred" for comparative studies. The service quality variable is represented by the operating safety metric *vehicle miles between collision accidents* (Stuart 1997; Fielding 1992). Safety is considered a key indicator of how transit service quality is defined by riders (Pullen 1993; Silcock 1981); number of collision accidents (as opposed to number of total accidents) is used in the denominator because collision accidents are reported more reliably in the Section 15 data (Fielding 1987, p. 77).

The variety of input and output variables comprising the systems model described above may appear to preclude their combination in one performance measure of transit services. However, a single measure of relative transit system performance can be constructed through the use of mathematical optimization methods so that the multiple inputs and outputs of the systems model can be considered simultaneously. The calculation of this overall performance metric is described in the following section.

Mathematical Formulation of the Systems Model

A mathematical formulation of this systems model for transit performance can be accomplished through a mathematical programming model known as Data Envelopment Analysis (DEA), originally proposed by Charnes, Cooper, and Rhodes (1981). DEA can be used to determine the relative efficiency of each member of a set of comparable transit agencies by computing for each transit system a ratio of weighted resource input values to weighted service output values. For each transit system, the DEA procedure will select the input and output weights that maximize the relative efficiency ratio for that system. Since the transit systems within a peer group use different combinations of resource inputs to provide different levels of service outputs, the weights produced by the DEA procedure will vary from system to system. However, all

DEA-generated weights will be nonnegative and any peer system could apply the weights for a specific system to calculate its own performance ratio, which would be less than or equal to 1 in value (Sexton 1986, p.10).

The following is a formal mathematical model for the DEA procedure:

$$\text{Max } h_k = \frac{\sum_{r=1}^{3} u_{rk} y_{rk}}{\sum_{i=1}^{3} v_{ik} x_{ik}}$$

$$\text{subject to: } \frac{\sum_{r=1}^{3} u_{rk} y_{rj}}{\sum_{i=1}^{3} v_{ik} x_{ij}} \leq 1$$

where: $j = 1, \ldots\ldots, n$

$$u_{rk}, v_{ik} \geq o;\ r = 1, 2, 3;\ i = 1, 2, 3$$

where:

x_{ij} = observed amount of input i used by j^{th} transit system,
y_{rj} = observed amount of output r generated by j^{th} transit system,
h_k = relative efficiency score for transit system k,
u_{rk} = weight for output r used by transit system k,
v_{ik} = weight for input i used by transit system k,
n = number of transit systems compared.

The objective function for *transit system k* is expressed in fractional form, with the numerator equal to the weighted sum of *annual revenue capacity miles, unlinked passenger trips,* and *vehicle miles between collisions*. The denominator is the weighted sum of *annual labor costs, fuel/materials costs,* and *fleet size.* The maximum value of this ratio (h_k) is the performance measure for *system k.* The *n* fractional constraints indicate each of the *n* peer transit systems would have a performance ratio less than or equal to 1 if *system k*'s input/output weights were used to construct the ratio. The remaining constraints in the model indicate that the weights for *system k*'s inputs and outputs are nonnegative.

Since there are *n* peer transit systems to be compared, *n* performance ratios must be computed; this requires *n* iterations of the model shown above (one iteration per transit system). The DEA model ensures that the optimal performance ratio (h_k) for each transit system will be a number between 0 and 1, with higher ratios indicating higher overall performance. If *transit system k* has a ratio less than 1 (i.e., $h_k < 1$), then that system is said to be *relatively inefficient* in converting multiple system inputs into multiple outputs. Charnes, Cooper, and Rhodes (1981, p. 669) define a system as *inefficient* if "it is possible to augment any output without increasing any input and without decreasing any other output" or "decrease any input without augmenting any other input or without decreasing any outputs." Thus, inefficient systems consume too much input (relative to efficient systems) in producing their outputs.

While DEA appears to be an attractive technique for optimizing transit performance, its usefulness has remained largely unrecognized in the transportation literature. Notable exceptions include studies by Kusbiantoro (1985); Chu, Fielding, and Lamar (1992); Kerstens (1996); and Nolan (1996). Kusbiantoro's work analyzed transit systems exhibiting a wide range of average operating speeds and peak-to-base ratios. Since these systems were not truly comparable, the study violated a requirement of DEA that systems are similar. Kerstens (1996) and Nolan (1996) focused on system efficiency only and formulated a single output DEA model to measure transit performance. Chu, Fielding, and Lamar (1992) proposed two separate DEA models to investigate transit system efficiency and effectiveness. Each model contained only one service output. In the first DEA model, annual vehicle revenue hours was the output variable used to examine the issue of service efficiency. In the second DEA model, service effectiveness was investigated through the use of annual unlinked passenger trips as the output variable. Although Chu, Fielding, and Lamar (1992) recognized the importance of modeling both transit efficiency and effectiveness, they did not attempt to combine these constructs into a single measure of system performance, as called for in the literature (Pullen 1993; Obeng, Assar, and Benjamin 1992). In contrast, the DEA model given above encompasses both concepts while simultaneously accounting for quality variables.

Model Application

The DEA/systems model was used to analyze the overall performance of a set of 27 peer transit systems operating in the United States. Fielding's (1987) typology for bus transit was used to classify these 27 systems as peers. The variables used by Fielding to create this typology were size, peak-to-base operating ratio, and average operating speed. All 27 systems served small cities (with populations between 50,000 and 145,000) and no system required more than 25 vehicles for peak service. Furthermore, each system in the peer group had an operating peak-to-base ratio of 1.45 or less and an average operating speed between 11 and 16 miles per hour. Thus, these bus systems were comparable and the DEA model, which assumes similar systems, could be applied (Fielding 1987, p. 46).

DEA results revealed that 21 of the 27 bus systems analyzed had performance ratios less than 1; therefore, these 21 systems were relatively inefficient in converting input resources (labor, fuel/materials, and capital) into service outputs (see Table 2). The remaining 6 systems, which had performance ratios equal to 1, are referred to as boundary points. A system that corresponds to a boundary point is a *relatively efficient* system only if the slack variables from the associated dual linear program are all 0 (or, equivalently, if the constraints from the dual program hold at equality). Table 2 shows that 6 transit systems have performance ratios equal to 1 as well as 0-valued slacks. Thus, these 6 systems display the highest relative performance in the group of 27 transit systems.

Once the relatively efficient systems have been determined, dual model results from the DEA procedure can be used to gain additional information about the inefficient systems. The solution for the dual program for an ineffi-

Table 2
Performance Ratios and Slack/Surplus Variables by Transit System

Transit System	*Performance Ratios*	*Vehicle Miles between Collisions*[a]	*Unlinked Passenger Trips*[a]	*Capacity Miles*[a]	*Labor Cost*[a]	*Fuel/ Materials Cost*[a]	*Fleet Cost*[a]
Efficient Systems							
Bloomington BPT, IL	1.0000	0	0	0	0	0	0
Eau Claire, WI	1.0000	0	0	0	0	0	0
La Crosse, WI	1.0000	0	0	0	0	0	0
LA Culver, CA	1.0000	0	0	0	0	0	0
Pensacola, FL	1.0000	0	0	0	0	0	0
Tuscaloosa, AL	1.0000	0	0	0	0	0	0
Inefficient Systems							
Abeline AT, TX	0.6430	22.19	0	0	0	0	0
Athena ATS, GA	0.9066	290.2	0	0	0	0	0
Beloit, WI	0.7729	80.82	0	4.74	0	0	0
Burlington, VT	0.5300	1.49	0	0	0	$53.71	4.10
Cumberland, MD	0.9184	318.25	0	0	0	0	0
Fayetteville–East, NC	0.7484	0	0	0	$7.06	$263.54	0
Galveston–Island, TX	0.8229	114.74	0	0	0	0	0
Glenn Falls, NY	0.07895	0	0	2553.33	0	5.71	0
Greenley, CO	0.8328	0	139.71	3037.11	0	$211.68	0
Hagerstown, MD	0.7225	201.45	20.51	0	0	0	0
Jackson, TN	0.8664	252.34	312.75	0	0	0	0
LaFayette–COLT, LA	0.8422	0	0	0	0	$71.81	0
LA Norwalk, CA	0.9272	25.84	1118.41	0	0	0	0.72
Lynchburg, VA	0.9581	76.82	0	0	0	$149.13	2.69
Monroe–MTS, LA	0.9906	0	0	0	0	$114.15	2.64
Portland Metro, OR	0.7754	2.38	0	0	$2.03	0	0
Rockford–Lanes, IL	0.9525	0	27.43	0	$39.45	$12.71	0
St. Cloud Metro, MN	0.8494	105.17	0	0	0	0	0
St. Joseph, MO	0.7936	125.01	281.08	0	0	0	0
Wilmington–WT, NC	0.9590	0	0	0	$15.52	0	0
Williamsport, PA	0.8873	95.87	0	0	$3.57	0	0

[a] In thousands.

Table 3
Actual Values for Input/Output Variables for Hagertown's Reference Set

System i	λ_i	*Labor Cost*[a]	*Fuel/Materials Cost*[a]	*Fleet Size*[a]	*Revenue Capacity Miles*[a]	*Unlinked Passenger Trips*[a]	*Vehicle Miles between Collisions*[a]
Bloomington	0.34027	\$446.00	\$29,256.00	14	39,853.60	858.20	223.60
Eau Claire	0.04735	\$466.00	\$13,798.00	12	24,553.80	846.30	495.90
Tuscaloosa	0.43597	\$536.00	\$8,011.00	6	13,688.90	381.50	290.00

[a] In thousands.

cient transit system furnishes a set of efficient systems known as an *efficient reference set* which can be used to identify inefficiencies in that system's use of inputs. For instance, DEA results showed that the Hagerstown system had a performance ratio of 0.7225, which is clearly inefficient (see Table 2). The transit systems for Tuscaloosa, Eau Claire, and Bloomington BPT formed the efficient reference set for this inefficient system because the dual variables (or lambda values) associated with these three systems are non-0 in the dual version of the DEA program for Hagerstown. The actual resource input values and output levels for Tuscaloosa, Eau Claire, and Bloomington BPT are shown in Table 3; also listed are the lambda values (λ_i) for these three systems. Table 4 shows the actual and projected values for the input and output variables for the Hagerstown system. Each projected input (output) value is a linear combination of the actual values on that variable used by Tuscaloosa, Eau Claire, and

Table 4
Actual and Projected Input/Output Variables for Hagertown's System

	Labor Cost[a]	*Material Cost*[a]	*Fleet Size*[a]	*Revenue Capacity/Miles*[a]	*Unlinked Passenger Trips*[a]	*Vehicle Miles between Collisions*[a]
Actual values	\$564.00	\$19,516.37	11	20,691.50	477.90	24.55
Projected values	\$407.50	\$14,101.00	8	20,691.50	498.41	226.00

[a] In thousands.

Bloomington BPT and the corresponding lambda values. For example, for the Hagerstown system:

$$\text{Projected labor cost (in thousands)} = \$407.5 = [0.34027(446.0) + .04735(466.0) + 0.43597(536.0)] \quad (1)$$

Similar computations yield the other projected values given in Table 4.

Table 4 indicates that, within the context of this particular model, the Hagerstown system is a relatively inefficient system because it consumes an excess of resources (labor costs, fuel/materials cost, fleet size) while underproducing two outputs—*unlinked passenger trips* and *vehicle miles between collisions*. Thus, the DEA results can be used within a systems approach to transit performance to help explain why a particular system is a relatively inefficient one.

In interpreting DEA results, it is advisable to examine how relatively efficient systems earned their maximum ratios. Within a group of peer transit systems it is possible to have "specialist" systems that concentrate exclusively on improving a single output variable. For instance, a transit system may emphasize *service provided* (an efficiency metric) to a far greater degree than the other systems in its peer group but exhibit mediocre *service consumption* (effectiveness) and *quality* metrics, compared to peer systems (Chu, Fielding, and Lamar 1992). Such "variations in emphasis between different authorities' objectives, as expressed in the output measures, are perfectly legitimate" in DEA modeling (Smith and Mayston 1987, p. 188). However, DEA will assign a ratio of 1 to this "specialist" system because its performance in *service provision* eclipses that of its peer systems, given the level of input resources used. Giokas (1991) and Smith and Mayston (1987) note that the efficient reference sets of *inefficient systems* differentiate "specialist" systems from "robustly efficient" systems (i.e., those systems whose maximum ratings do not result solely from superior performance on a unique output measure). A system that appears to be relatively efficient but does not belong to the efficient reference set of any inefficient system is a "specialist." Since the La Crosse system is not contained in the efficient reference set of any inefficient system in this study, it is a specialist system. Examination of actual data values reveals that, given its use of resource inputs, the La Crosse system exhibits outstanding performance on only one output variable—annual revenue capacity miles.

Discussion

This study proposed a systems-based model of transit performance that links multiple inputs to the core service outputs of quality, efficiency, and effectiveness. A single metric of relative overall performance is developed using a DEA formulation of the systems model. Not only does the DEA methodology furnish a performance measure that may prove useful to elected officials, transit personnel, media, taxpayers, and other stakeholders in a particular transit system, it also helps to explain, via analysis of the dual problem, why a particular system with a low rating is relatively inefficient. Dual problem analysis also helps to identify specialist systems, which attain the maximum rating due to outstanding performance on one aspect of service delivery.

The systems approach presented in this research is unique in that it models transit output as a multidimensional vector consisting of service quality, service provision, and service consumption. Previous systems models of transit performance (e.g., Fielding 1987; Chu, Fielding, and Lamar 1992) used a sequential approach, depicting service provision as an input to service consumption. For instance, in Chu, Fielding, and Lamar's (1992) study, two DEA models are used sequentially to evaluate performance. In the first DEA model (the efficiency model), service provision is the sole output variable while in the second DEA model (the effectiveness DEA), service provision is one of the inputs linked to service consumption, the single output variable.

The problem with this sequential modeling of transit service is that in actual transit operations it is possible to improve service quality and consumption without ever altering the level of the service provision variable. For example, a bus without air-conditioning during a heat wave may discourage ridership without ever affecting the number of vehicle operating hours compiled (service provided). Fixing the broken air-conditioning system will improve riders' perceptions of transit quality and encourage them to use the service again (thereby increasing consumption). In this example, labor and repair supplies and parts directly affect transit consumption and quality without affecting vehicle operating hours (the output of the "efficiency DEA" in sequential DEA modeling). In general, a single DEA model that links input resources to the multiple outputs of service quality, service provision, and service consumption better exploits the power of DEA methodology to identify inefficiencies than a series of single output DEA models.

While DEA provided a useful mathematical realization of the systems model of transit performance presented in this article, there are several considerations regarding its application that should be taken into account. First, DEA is sensitive to data inaccuracies, particularly if these involve efficient systems. Use of unreliable or misspecified data for these systems can affect the performance ratios of the remaining peer systems. (All data used in the DEA model are found in the *National Transit Database,* which Chu, Fielding, and Lamar [1992, p. 223] label "a superb national data set" in which "variables are appropriately defined and validated.") Second, omission of an important output variable from the model will distort the DEA results (Smith and Mayston 1987, p. 188). For instance, if *service provided* is modeled as the sole output of transit performance, systems that excel in service quality and effectiveness could unfairly be characterized as relatively low performers. Third, inclusion of too many variables will also distort DEA results; therefore, sample size must be adequate given the total number of variables used. Golany and Roll (1989) and Fitzsimmons and Fitzsimmons (1994, pp. 321–322) suggest that the number of systems analyzed should exceed twice the sum of all input and output variables. (In this study, the number of transit systems [27] was greater than twice the sum [6] of model variables.)

The specific DEA model discussed in this article serves as an example of the systems modeling approach for transportation performance evaluation. Clearly, this particular model is not without limitations. While this specific model utilized labor costs, fuel/materials costs, and fleet size as inputs, other input variables such as subsidies and expenditures on facilities, signage, shelters, and advertising could be added to future research models. Similarly, other measures of service quality could be included as output variables. These metrics could be drawn from operating data or be based on customer perceptions of service quality that are captured through onboard surveys, phone interviews, focus groups, etc. These service variables could encompass a variety of transit service issues including reliability, driver courtesy, security, and service accessibility. Greater refinement of the topology for peer transit systems constitutes another area for future research. While this study utilized Fieldings's (1987) taxonomy, additional classification variables may serve to further differentiate transit systems. Such variables include geography, demographics, climate, congestion, and availability of parking.

In summary, the systems approach to transit performance can provide a potentially useful tool for simultaneously modeling service inputs and the key service outputs of service quality, transit efficiency, and effectiveness. Through the use of DEA modeling, multiple criteria can be summarized with a single overall measure of transit system performance. This measure may be of value to a variety of stakeholders in a local transit system.

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References

Abbas, K. A., and M. G. H. Bell. 1994. System dynamics applicability to transportation modeling. *Transportation Research A* 28A (5): 373–400.

Briddell, E. T., and M. B. Arden. 1998. How to build a better transit system. *Mass Transit* 24 (2): 21–27.

Charnes, A., W. W. Cooper, and E. Rhodes. 1981. Evaluating program and managerial efficiency: An application of data envelopment analysis to program follow through. *Management Science* 27 (6): 668–697.

Chu, X., G. J. Fielding, and B. W. Lamar. 1992. Measuring transit performance using data envelopment analysis. *Transportation Research* 26A (3): 223–230.

Cunningham, L. F., C. E. Young, and M. Lee. 1997. Developing customer-based measures of overall transportation service quality in Colorado: Quantitative and qualitative approaches. *Journal of Public Transportation* 1 (4): 1–21.

Fielding, G. J. 1987. *Managing public transit strategically.* San Francisco: Jossey-Bass, Inc.

Fielding, G. J. 1992. Transit performance evaluation in the U.S.A. *Transportation Research A* 26A (6): 483–491.

Fielding, G. J., R. E. Glauthier, and C. A. Lave. 1978. Performance indicators for transit management. *Transportation* 7 (4): 365–379.

Fitzsimmons, J., and M. Fitzsimmons. 1994. *Service management for competitive advantage.* New York: McGraw-Hill.

Giokas, D. 1991. Branch bank operating efficiency: A comparative application of DEA and the loglinear model. *Omega* 19 (6): 549–557.

Gleason, J. M., and D. T. Barnum. 1982. Toward valid measures of public sector productivity: Performance measures in urban transit. *Management Science* 28 (4): 379–386.

Glossary of Transit Terms. 1990. U.S. Department of Transportation, Federal Transit Administration.

Golany, B., and Y. Roll. 1989. An application procedure for DEA. *Omega* 17 (3): 237–250.

Hatry, H. P. 1980. Performance measurement principles and techniques: An overview for local government. *Public Productivity Review* 4: 312–319.

Kerstens, K. 1996. Technical efficiency measurement and explanation of French urban transit companies. *Transportation Research A*, 30 (6): 431–452.

Kusbiantoro, X. 1985. A study of urban mass transit performance: Concept, measurement, and explanation. Unpublished Ph.D. dissertation. University of Pennsylvania, Philadelphia, Pennsylvania: The School of Public and Urban Policy.

Nolan, J. F. 1996. Determinants of productive efficiency in urban transit. *Logistics and Transportation Review* 32 (3): 319–343.

Obeng, K., N. Assar, and J. Benjamin. 1992. Total factor productivity in transit systems: 1983–1988. *Transportation Research A* 26A (6): 447–455.

Obeng, K., and I. Ugboro. 1996. Applications of TQM in public transit firms. *Transportation Quarterly* 50 (3), Summer: 79–94.

Pullen, W. T. 1993. Definition and measurement of quality service for local public transport management. *Transport Reviews* 13 (3): 247–264.

Sexton, T. 1986. The methodology of data envelopment analysis. In *New Directions for Program Evaluation*. R. H. Silkman., ed., San Francisco: Jossey-Bass, 31–46.

Silcock, D. T. 1981. Measures of operational performance for urban bus services. *Traffic Engineering and Control* 22 (12): 645–648.

Smith, P., and D. Mayston. 1987. Measuring efficiency in the public sector. *Omega* 15 (3): 181–189.

Stokes, B. R. 1979. The need for and use of performance indicators in urban transit. *Transit Journal*. Winter: 3–10.

Stuart, D. G. 1997. Goal-setting and performance measurement in transportation planning and programming. *Journal of Public Transportation* 1 (2): 49–71.

Sulek, J. M., M. R Lind, and A. S. Marucheck. 1995. Improving service quality through customer input. Proceedings of the 1995 Meeting of the Decision Sciences Institute. Boston, MA: November 20–22: 1590–1592.

Takyi, I. K., K. Obeng, and I. Ugboro. 1993. Total quality management for public transit systems. T*ransportation Quarterly* 47 (2): 167–183.

Talley, W. K. 1988. An economic theory of the public transit firm. *Transportation Research* 22B (1): 45–54.

Talley, W. K., and P. P. Anderson. 1981. Effectiveness and efficiency in transit performance: A theoretical perspective. *Transportation Research A* 15: 431–436.

Talvitie, A. P., and K. Obeng. 1991. Productivity and performance. *Transportation Planning and Technology* 15: 169–176.

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Issues on the Application of an Advanced Public Transit System to Dial-a-Ride Service

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Abstract

The Federal Transit Administration's Advanced Public Transportation System (APTS) program consists of demonstration projects that illustrate the use of new technologies in public transit. In view of the fact that similar systems are beginning to use new technology to locate and dispatch vehicles, this article reports on a study that examined issues that must be considered in implementing new systems. Specifically, the study focused on initial parameters for the computer program, defining and accessing these parameters in relation to quality of service, and measuring rider responses to guarantee performance.

The implications of these issues for service quality were examined for the APTS demonstration project in Winston-Salem, North Carolina. The study analyzed consumer response to the Mobility Manager, a Geographic Information System (GIS) applied to the site's demand-responsive minibus service for the elderly and people with disabilities. Survey data from two questionnaires issued before and after the implementation of the Mobility Manager were utilized to examine travel behavior and perceived service quality. In addition, data from driver manifests issued after implementation of the Mobility Manager are used to clarify results.

Introduction

This article examines three key issues that affect service provided by an APTS:

1. Selection of the appropriate software (see, for example, Stone et al. 1993).
2. Establishment of the initial parameters in terms of quality of service provided each day and level of service desired.
3. Assessment of daily service quality as perceived by users of the service.

In particular, the article reports on a study of the Mobility Manager APTS demonstration project in Winston-Salem, North Carolina. The study first looked at the key initial parameters used during implementation of the Mobility Manager. Next, it investigated changes in the quality of service performance, as indicated by consumer responses before and after implementation and confirmed results with driver manifest data. The study focused on service characteristics derived from the Code of Federal Regulations, Title 49, Part 37, including travel time, on-time performance, and acceptance of travel requests. Trip rates were used as a surrogate for acceptance of travel requests.

The APTS program of the Federal Transit Administration involves projects that demonstrate application of advanced technologies in transit systems (Casey et al. 1991). This article focuses on the site's TransAID operations, a minibus dial-a-ride service for special populations in Winston-Salem. TransAID utilizes new transit technologies including automated computer dispatch, automatic vehicle location, and smart cards. Taken together, these technologies make up the Mobility Manager—a GIS combined with a management information system that assists the transit agency in scheduling, routing, billing, and administration.

TransAID services are provided in eight 15-passenger minibuses (vans) equipped for nondisabled passengers and 11 vans equipped for wheelchairs. The system operates in Forsyth County, which includes Winston-Salem, from 5:30 A.M. to 6:30 P.M. during weekdays. Limited service is provided for dialysis patients on Saturdays. No fare is charged for the TransAID service. The study analyzed TransAID services in 1994, the year the Mobility Manager was implemented, and 1996. The dial-a-ride system operated 12 vehicles in maximum service during these two years. In the study years, annual passenger miles decreased from 955,328 to 435,959 and trips per vehicle-revenue mile decreased from 0.46 to 0.30 (Federal Transit Administration 1994, 1996).

The Mobility Manager provides each driver with a computer-generated daily detailed schedule. As part of the study, the schedule was manually reviewed for missed appointments and operating efficiency. Two key parameters for the analysis were the maximum travel time of 2 hours and the pickup time window of 20 minutes. Manifests were reviewed for scheduling errors with the possibility of a manual override when necessary.

The Mobility Manager was intended to improve service quality. In particular, it was designed to enhance the system's telephone response service. Confirmation of reservations was expected to be immediate, travel time would be reduced, and pickup and dropoff times would be more accurate.

Study Design

This section presents findings from before and after studies of consumer responses along with their comparison to vehicle scheduling information acquired in October 1997. An initial analysis of service evaluations presented in Benjamin et al. (1997) was inconclusive. Spring et al. (1997) investigated the performance of system components for the Mobility Manager and the results also showed no service improvements.

The Mobility Manager's effectiveness depends on the efficiency of the automated routing and scheduling system. The capabilities of automated dispatching systems for dial-a-ride services have been studied for more than two decades. Lerman and Wilson (1974) and Lerman et al. (1977) discuss initial attempts at computer-automated dispatching. Based on comparisons to a computer simulation, these studies reported a 10 to 20 percent reduction in average travel time from automated routing and scheduling procedures. These studies also noted that the first automated system application provided travel times comparable to manual schedules but with more reliability for on-time pickup and delivery.

Three Data Sets

Three different data sets were used in the current study. These include:

- survey data (the before study) of rider travel before implementation of the Mobility Manager was completed in the summer of 1994,
- survey data (the after study) that replicated the before study with the same subjects two years later (1996), and
- driver manifest records from a week in the fall of 1997 that were selected at random by the transit authority.

User questionnaires consisted of three parts:

1. Respondents were asked how they traveled during the last week (number and purpose of all trips using the dial-a-ride service). The time frame of a week was chosen because of the low daily trip rate for these subjects.
2. Respondents were asked to provide details about the last time they traveled including travel time, on-time pickup and arrival, and about reserving the trip.
3. Respondents were asked about their background (gender, age, income, and mobility-related disabilities).

Driver manifests were used to compare planned and actual travel times to reported times from the survey data to confirm reported results and to determine operation details. Planned times were provided as computer output and actual times were entered by the drivers. Driver manifests were used because the survey recorded riders' perceptions. The manifests were considered to be more accurate and allowed an evaluation of what travel times were planned by the system and not due to traffic or other factors. Cross-sectional comparisons were possible because all samples were random.

In addition, the time to complete the direct trip (base time) was used to evaluate the planned schedule. Although it was anticipated that travel time was longer for shared-ride service, the base time provided an idea of how much extra time was required and whether the extra time was related to the direct distance of the trip.

The second survey was performed two years after implementation of the Mobility Manger. This lag gave both riders and operators time to adjust to the system and to measure more accurately its full impact.

Survey Respondent Descriptions

The before-study survey was completed by 272 TransAID riders, of which 176 were still service users at the time of the after study, and were contacted by mail to participate in the after study. Of the 176 people, 162 responded to the after study, and 101 surveys were completed (Table 1).

General Socioeconomic Statistics

The initial data analysis was presented by Benjamin et al. (1997). A summary of sociodemographic descriptions of respondents is presented in Table 2. Note that disabilities are not mutually exclusive and some riders have more than one disability.

The lack of significance of all of these χ^2 statistics indicates that in a comparison of the characteristics between the before and after studies there is no

Table 1
Respondents' Survey

Measure	*Level*	*Frequency*	*Percent*
Surveys	Complete	100	62
	Incomplete	62	38
	Total	162	100
Measure	*Level*	*Frequency*	*Percent*
Incomplete	Doesn't use service	14	23
	Phone disconnected	13	21
	No contact	12	19
	Doesn't live at this phone	9	15
	Deceased	8	13
	Nonpublished phone	2	3
	Not interested	2	3
	No recollection	2	3
	Total	62	100

Table 2
Respondent Sociodemographics

		Before Study		After Study	
Measure	*Levels*	*Frequency*	*Percent*	*Frequency*	*Percent*
Age	18–39	19	8.09	1	1.02
	40–64	54	22.98	26	26.53
	More than 64	162	68.94	71	72.45
	Total	235	100.00	98	100.00
	$\chi^2 = 0.41$	$p = 0.52$			
Measure	*Levels*	*Frequency*	*Percent*	*Frequency*	*Percent*
Education	Elementary	76	35.68	29	31.18
	High School	110	51.64	49	52.69
	College	27	12.68	15	16.13
	Total	213	100.00	93	100.00
	$\chi^2 = 0.96$	$p = 0.62$			
Measure	*Levels*	*Frequency*	*Percent*	*Frequency*	*Percent*
Employment	Employed	5	2.26	2	2.02
	Unemployed	216	97.74	97	97.98
	Total	221	100.00	99	100.00
	$\chi^2 = .02$	$p = .89$			
Measure	*Levels*	*Frequency*	*Percent*	*Frequency*	*Percent*
Disability	Seeing	95	42.99	12	12.12
	Hearing	101	45.70	4	4.04
	Grasping	81	33.65	16	16.16
	Walking	139	62.90	65	65.65
	Wheelchair	83	37.56	26	26.26
	Total	221	100.00	99	100.00
	$\chi^2 = 42.4$	$p = .00$			

statistically significant difference for age, education, and employment. Further, there are few people who were employed in both studies.

Service Usage and Quality

Responses before and after implementation of the Mobility Manager were analyzed to determine service utilization and quality. For this group, 45 percent of riders rode TransAID the week before the first survey but only 30 percent used the service the week before the second survey. The trips reported were unequally distributed between days of the week. The largest number traveled on Monday (47%), with other trips distributed over the remaining portion of the week. Only 2 percent of the sample rode on Saturday, and no service was provided on Sunday. Similar results were reported in the second survey.

Table 3 shows trips made by disability and trip purpose. Of these trips, 76 percent of the before-study (74.4% of the after-study) group traveled for medical reasons. The majority rode for medical reasons in each disability group in the before and after studies and the disability group with the largest percentage of medical trips was for those people who had difficulty walking. Virtually all of the trips were round-trips, and most people traveled by TransAID only once during the week. The average number of trips by all modes reported during the survey week was 2.8 in the before study and 3.8 in the after study. Only one-third of the respondents made a second round-trip, and about one-fourth made more trips. Thirty-seven users made five round-trips, and only one rider reported making a sixth trip (for a medical purpose) before and, at most, five round-trips after. The χ^2 test for independence of the distributions of trips in the before and after studies was significant, which may be related to differences in reported disabilities.

Table 3
Percent of Weekly Trips by Disability and Trip Purpose

Trip Purpose	*Before Study*					*After Study*				
	I	*II*	*III*	*IV*	*V*	*I*	*II*	*III*	*IV*	*V*
Medical	70.3	100.0	61.2	83.6	70.5	63.2	100.0	63.0	83.8	54.4
Other	29.7	0.0	39.8	16.4	29.5	36.8	0.0	37.0	16.2	45.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Observations	23.0	8.0	34.0	131.0	87.0	8.0	1.0	20.0	59.0	13.0
Trips	74.0	20.0	93.0	341.0	146.0	19.0	1.0	27.0	74.0	22.0

I	Difficulty seeing
II	Difficulty hearing
III	Difficulty reaching and grasping
IV	Difficulty walking
V	Uses a wheelchair

$\chi^2 = 50.0, p = .0$

Change in Service Usage Patterns after the Mobility Manager

Table 4 summarizes travel by trip purpose and age group. Only adults between the ages of 18 and 65 have a significant amount (about 20%) of educational trips.

Service was requested at a minimum of 24 hours in advance during the before study with a no same-day requests after despite the addition of that option during the after study.

Table 4
Trip Purpose by Age Group (among all one-way trips)

Trip Purpose	*Age*			
	Before Study		*After Study*	
	18–65	*Over 65*	*20–67*	*Over 67*
Medical	78.3	72.0	71.2	60.0
Other	21.7	28.0	28.8	40.0
Total	100.0	100.0	100.0	100.0
Observations	77.0	154.0	35.0	63.0
Tours	111.0	202.0	59.0	90.0
	$\chi^2 = 4.34$	$p = .23$		

For respondents more than 65 years old in the before study, 72 percent of the trips were made for medical purposes. For the above 65-year-old group, other trip purposes included shopping and nutrition, with each representing about 10 percent of the trips, demonstrating that TransAID was helping with their daily activities. The χ^2 test for dependence of the distribution of trip purposes from the before and after studies was not significant, indicating stable travel patterns.

Comparison of Service Characteristics before and after Implementation of the Mobility Manager

Three sets of data were used to examine improvements in service characteristics: travel time, on-time service, and trip rates as a surrogate for accessibility. Three data sets were available for the first two measures: the complete original data set, panel data (with attrition), and observations from driver manifests. Cross-sectional analyses were completed with the original data set and the after-panel data because of the difference in respondents due to attrition. Panel data were tested because of advantages in providing more precise results and cross-sectional analyses were conducted with observations from driver manifests to clarify the after results. Only statistics for adults 18 years and older in the before study, age 20 and older in the after study, and the driver manifests are reported.

Analysis of Changes in Travel Time

Travel time statistics for the initial total sample, for the responses of subjects who continued with the panel before and after the project, and observations from driver manifests are presented in Table 5. There was an increase in average travel time for comparisons between cross-sectional before data and recent driver manifest data (22.8 to 36.2 minutes with $t = 5.51$), between cross-sectional before data and the after-panel subsample (22.8 to 27.3 minutes with $t = 2.06$), and between responses given by panelists before and after project initiation (a difference increase of 7.5 minutes with $t = 3.1$). All of the differences were significant at the 5 percent level. The observed maximum planned time is almost three hours (173 minutes)—almost one hour more than the maximum reported before time and the initial heuristic parameters. These time increases

Table 5
Reported and Observed Travel Time Changes

Parameter	*Survey Data*				*Manifest Data*		
	Total Sample	*Panel*					
	Before Study	*Before Study*	*After Study*	*Difference*	*Planned*	*Actual*	*Base*
Mean	22.8	20.4	27.3	7.5	38.6	36.2	10.2
Maximum	240.0	120.0	90.0	55.0	173.0	105.0	6.0
Minimum	0.0	0.0	5.0	-100.0	1.0	0.0	32.0
Standard deviation	23.0	15.8	15.6	19.9	23.5	29.7	0.0
Number of cases	194.0	85.0	77.0	68.0	428.0	491.0	10.0

are meaningful and are evidence that intended service improvement for riders was not achieved.

Detailed Analysis of Passenger Travel Time after Implementation of the Mobility Manager

Table 5 also presents summary measures of planned travel time by the Mobility Manager that were taken from recent manifests and base travel time, which is the travel time for a direct trip based on the MAPQUEST GIS shortest route (GeoSystems, 1998). On average, a passenger requested service for a trip of 4.1 miles, which takes 10.2 minutes (base travel time). The passenger was initially scheduled to be on a vehicle for 38.6 minutes on average, while actually he or she was on a vehicle for 36.2 minutes on average.

There are substantial variations among base travel time with a median base time of 10 minutes, indicating that most service requests are for relatively short trips within the city limits. The longest trip request takes 32 minutes, while the shortest request takes less than 1 minute (0.1 mile).

Actual travel time is much longer than the base travel time: 36.2 minutes on average, with a maximum of 105 minutes, a minimum of 0 minute, and a median of 30 minutes. In the trip with the longest actual travel time, a passenger requested a 5.5-mile trip, which takes 11 minutes base travel time, but actually took 105 minutes. A detailed inspection of the manifest revealed that the passenger was among seven passengers picked up at the same origin. The vehicle picked up four more passengers at the next stop. Finally, the passenger was dropped off ninth, after all other six passengers picked up at the first origin with her had already been dropped off and two other passengers picked up at the second stop had been dropped off. As a result, she traveled 42 miles and was on the vehicle for 105 minutes.

The actual travel time is clearly the result of the planning process using the Mobility Manager. Study data reveal that the average planned travel time is 38.6 minutes, which is slightly longer than the average actual travel time, with a maximum of 173 minutes (nearly 3 hours). Again, the researchers looked closely at the case of the longest planned travel time. The passenger requested a 5.0-mile trip, which takes 13 minutes base travel time, but he was scheduled to take a 173-minute trip. He was among 12 passengers scheduled to be picked up at the same origin, and scheduled to be dropped off last. Thanks to five cancellations, he was actually on the vehicle for 80 minutes. Furthermore, of 11 passengers with him, 3 requested longer trips (base travel time) than his.

The overall effect of the Mobility Manager is illustrated in Table 6. The table presents travel time for multiple shared-ride trips and for single passengers. In this table, the average actual travel time for riders who travel without other passengers is significantly less than for riders who travel with multiple passengers (26.7 compared to 40.1 minutes with $t = -3.16$).

Table 6
Travel Time for Multiple Passengers versus Single Passengers

	Multiple Passengers			*Single Passengers*		
	Base Time	*Actual Time*	*Planned Time*	*Base Time*	*Actual Time*	*Planned Time*
Average	9.3	40.1	43.8	13.1	26.7	23.9
Standard deviation	5.3	24.8	31.5	6.1	16.6	16.9
Maximum	2.3	105.0	173.0	32.0	100.0	101.0
Minimum	0.0	0.0	1.0	0.0	5.0	4.0
Median	9.0	35.0	37.0	12.0	23.0	20.0
Sample size	330.0	303.0	362.0	107.0	125.0	129.0

Difference among Travel Times

To further emphasize the role of the dispatching procedure using the Mobility Manager, the difference between actual travel time and base travel time (actual extra travel time) was examined for each trip. The difference indicates how many extra minutes each passenger must be on a vehicle if the passenger chooses to use TransAID service rather than an alternative transportation mode.

Table 7 shows that, on average, the difference between actual travel time and base travel time is 26.4 minutes, with a maximum of 96 minutes. The difference may depend on the number of passengers picked up at the same origin or dropped off at the same destination (or number of passengers on a vehicle at the same time).

Table 7
Passenger Travel Time after Implementation of Mobility Manager

	Planned Travel Time Minus Base Travel Time	*Actual Travel Time Minus Base Travel Time*	*Actual Travel Time Minus Planned Travel Time*
Average	28.4	26.4	-2.1
Standard deviation	28.3	23.5	26.1
Maximum	160.0	96.0	92.0
Minimum	-9.0	-11.0	-99.0
Median	20.0	19.0	0.0

The difference between planned travel time and base travel time is 28.4 minutes on average, with 160 minutes maximum. These figures are both longer than the difference between actual travel time and base travel time, indicating that a long actual trip is not accidental, but actually scheduled to last long.

Because of unexpected cancellation of scheduled trips and unexpected request of unscheduled trips, the actual travel time could differ from the planned travel time, where the former factor reduces the actual travel time and the latter factor increases the actual travel time. On average, the difference is only -2.1 minutes. A negative average indicates that TransAID operation tends to schedule each trip slightly longer than it actually takes, though it is not statistically significantly different from 0. However, the individual's actual travel time could be 99 minutes shorter or 92 minutes longer than initially scheduled.

Analysis of Changes in Timely Arrivals

Transit authority policy of a 20-minute window applies specifically to pickup time at the origin. However, the ability to arrive at the destination in a timely manner is also important. The percent of people who reported arrival at the origin greater than the allowable 20 minutes before or after the scheduled time was 15.9 percent for the entire before sample; 12.0 percent, panel before sample; 14.3 percent, panel after study; and 34.6 percent, driver manifests. The *z* statistics for the reported comparisons of the complete before sample and the after panel and the panel data are 0.7 and -0.7, which are not significant at the 5 percent level. The manifest data, however, when compared to the after-reported data had a *z* statistic of 4.9, which is significant at the 5 percent level. In other words, the reported times were significantly smaller than the observed manifest data.

Delay time is defined as the difference between planned and actual arrival time at either the origin or destination. Delay time statistics are presented in Table 8. Delay time was analyzed for both pickup and arrival at the destination. For pickup, there was no significant difference in delay time. Despite the low average pickup delay, there were maximum delays of up to two hours that continued after implementation of the Mobility Manager that exceed the desired limits.

Further, an increase in average delay time at the destination was observed for the total before sample with the after-panel subsample (-4.2 to -20.0 minutes with $t = 3.10$), for the before- and after-panel subsample (-4.8 to -20.0 minutes with $t = 6.3$), and the total before sample with the manifest (-4.2 to -7.6 minutes

Table 8
Reported and Observed Delay Time

Parameter	*Reported*						*Observed*	
	Total Sample		*Panel*					
	Before Study		*Before Study*		*After Study*			
	Origin	*Destination*	*Origin*	*Destination*	*Origin*	*Destination*	*Origin*	*Destination*
Mean	-3.7	-4.2	-4.5	-4.8	-4.6	-20.0	-3.7	-7.6
Maximum	90.0	60.0	90.0	60.0	45.0	45.0	60.0	60.0
Minimum	-120.0	-120.0	-120.0	-180.0	-120.0	-120.0	-123.0	-123.0
Standard deviation	22.2	19.2	24.3	20.4	23.6	13.7	25.2	25.2
Number of cases	271.0	271.0	100.0	88.0	101.0	26.0	461.0	442.0

with t = 3.27). All of these t statistics are significant at the 5 percent level. Delays as much as two hours were observed for both reported times and times after implementation of the Mobility Manager.

Analysis of Changes in Trip Rates

Trip rate is the number of trips taken in a week. Trip rate responses were taken only from reported data and are summarized in Table 9. The trip rate increase for the panel was significant at the 5 percent level (t = 5.2) but the cross-sectional comparison was not significant. This indicates that the trip rates were stable for these subjects.

Table 9
Reported Number of Weekly Trips by TransAID Riders

Parameter	*Total Sample*	*Panel*		
		Before Study	*After Study*	*Difference*
Mean	1.8	1.4	1.9	1.4
Maximum	6.0	6.0	5.0	7.0
Minimum	0.0	0.0	1.0	-3.0
Standard deviation	1.5	1.2	1.2	2.0
Number of cases	251.0	93.0	56.0	56.0

Given a large overall attrition rate (63%), an insignificant increase in the trip rates per user resulted in less overall usage of the TransAID services during the study period, as indicated in decreases in annual passenger miles and trips per vehicle-revenue mile during the study period.

Conclusions

During the study period, there was little change in the environment. There was no change to the street network, passenger eligibility qualifications, fares, or management personnel. Little change occurred in the number and type of vehicles. There were no significant differences between age, education, and employment of the total before and after panel sample. However, since this is not a controlled experiment and detailed information on dispatching before the Mobility Manager is unavailable, the researchers must qualify their conclusions.

Several key findings emerged from this study. First, there is substantial attrition in the panel. While attrition in panel studies may be 10 percent, the total attrition here is 63 percent. This is large even if the small number of Head Start riders is considered. Of these subjects, there were only two refusals (less than 1%). Attrition may be due to changes in travel behavior over time, substitution of other modes, or the transient nature of the service population. The remaining users included a large number who moved or changed phone numbers. This suggests that future research on new transit technologies, such as the Mobility Manager, should oversample the relevant population.

Second, the results of the comparison of surveys suggest that implementation of the Mobility Manager in Winston-Salem did not clearly achieve the intended improvements, despite the potential for travel time reductions reported in earlier studies.

Third, for the three key variables identified by federal regulations (travel time, pickup delay time, and trip rates as a surrogate for accessibility), it was found that travel time increased, there was no change in pickup delay time (but a significant increase in dropoff delay time), and the trip rates remained stable for these subjects. The researchers believe there is a trade-off between travel time and efficiency. While individual performance measures decreased, overall system efficiency did not improve.

These performance results highlight the importance of the three issues mentioned earlier: input parameters that were used for the dispatching heuristic, regular monitoring of the service operation through driver manifests, and periodic review of consumer surveys.

Two parameters in the heuristic were critical. Maximum travel time was set at 2 hours and the pickup time window was 20 minutes. Setting parameters is one way to establish policy for an APTS. Careful review should be given to the setting of these parameters including input from riders.

These results suggest that service performance should be monitored daily. When computer manifests are available, their schedules may be reviewed daily and possible problems addressed by careful monitoring by trained personnel who can correct and manually improve scheduling errors. Manifest reviewers should be assisted by computer output that includes calculation of statistics to recognize problems (e.g., the travel and delay times that exceed predetermined limits) and flags to help find scheduling errors. Long travel times occurred when there were many additional stops during a shared ride. Daily summary statistics would serve to alert reviewers of persistent problems and assist in the review.

Also, users' views should be measured regularly to ensure that their perceptions on service quality are improving.

With automated dispatching becoming more widespread, this study suggests that the true potential of technologies, such as Mobility Manager, from the consumers' perspective is their ability to improve the perceived quality of service. Future implementation of technological improvements must consider the direct impacts on consumers.

Finally, several extensions and refinements are recommended for future studies. First, even though the researchers carefully controlled the before and after surveys, there always exist factors that change between the two periods and affect the survey results. Second, because the second survey was done two years after the first, changes due to aging of riders that may affect their health and comfort level should be taken into account. By measuring any health problems directly, their covariance can be controlled.

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References

Benjamin, J., Gregory N. Price, and William E. B. Nelson. January 1997. A case study of the impact of APTS on service quality perceptions. National Meeting of the Transportation Research Board, Washington, DC.

Casey, R., L. Labell, S. Prensky, and C. Schweiger. 1991. Advanced Public Transportation Systems: The state of the art. USDOT/FTA, Report Number DT-VNTSC-UMTA-91-2.

Federal Transit Administration. 1994, 1996. *Transit profiles.*

GeoSystems Global Corporation. 1998. MAPQUEST. www.mapquest.com.

Lerman, S. R., M. F. Flusberg, W. Pecknold, R. Nestle, and N. H. M. Wilson. December 1977. Method for estimating patronage of demand-responsive transportation systems. *Final Report*. Report No. DOT-TST-77-77, U. S. Department of Transportation.

Lerman, S. R., and N. H. M. Wilson. 1974. An analytic equilibrium model for dial-a-ride design. *Transportation Research Record 522*, 38–46.

Spring, G. S., J. Collura, and K. B. Black. 1997. Evaluation of automated vehicle location technologies for paratransit in small- and medium-size urban areas. Paper presented at the 76th Annual Meeting of Transportation Research Board, Washington, DC (Reprint No. 970201).

Stone, J. R., A. Nalevanko, and J. Tai. 1993. Assessment of software for computerized paratransit operations. *Transportation Research Record 1378*, 1–9.

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A Dynamic Competitive Environment and Shifting Management Paradigms: Implications for Marketing Public Transit Services

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Abstract

This article reports on the results of a telephone survey of 352 commuters who reside in a suburban area and work in a major city. Results indicate that the commuters are well educated and well paid. They also suggest that much of what has passed for marketing strategies in the transit industry has been ineffective at best. Solutions for the dilemma are identified and considered.

Introduction

The problems of organizations in decline are neither novel nor new. The product life cycle[1] has been offered as an explanation of this process, yet whole industries have fallen prey. American railroad firms did not recognize how their businesses were affected by changing economic and demographic environments and the emergence of airlines as a competitor. They have yet to regain market share, even while their European counterparts have retained their viability. The current analogy in the United States is public transit. Though it is widely acknowledged and documented that the public transit industry is in crisis, it has been slow to respond (Daft, Lengel, and Perdue 1998).

The crisis facing public transit is not unique. In the past two decades many industries have faced similar problems. Banking, insurance, retailing, and the defense industries all have experienced the pressures of government regulation, product obsolescence, information overload, changing family structures, and two-income households that have drastically intensified competitive pressures. As a result, firms in these industries have used restructuring, reengineering, mergers, acquisitions, joint ventures, and a variety of consumer-based strategic approaches to redefine their position in the marketplace (Daft, Lengel, and Perdue 1998).

In each case, success was brought about by the organization's willingness to embrace change. Managers had to realize that old methods and products were no longer acceptable alternatives in the new realities of the marketplace. Business paradigms—an organization's way of thinking, perceiving, and understanding its role in the marketplace (Daft, Lengel, and Perdue 1998)—had to be shifted. The crisis inherent today in the public transit industry is very much rooted in these pressures and the need for a "paradigm shift."

Background

In an effort to compete with the automobile, transit agencies have turned to marketing to increase the perceived value of their services. Rideshare, transit voucher, employee pass, and transportation coordinator programs all have had some success. However, the market orientation of public transit firms still lags behind the private sector. Being market oriented simply means maintaining a viable fit between an organization's objectives, skills, and resources, and its changing market opportunities (Kotler 1997). While there have been well-documented demographic, economic, and technological changes in U.S. markets, has the basic product offered by public transit organizations changed in the last decade? The last two decades? The last half century?

Although the programs mentioned above have met with some success, most have done so largely by adjusting the monetary cost of commuting. Price discounts are a short-term incentive only. Many larger issues still confront public transit properties. Is the service package, the bundle of benefits offered by public transit services, what today's commuter needs and wants? How do public policy issues such as air quality control and traffic congestion affect commuters' decisions?

Answers to these questions, as with all marketing decisions, start with the consumer. The study reported here examined the expectations of the new-millennium public transit consumer. By searching for new answers to old questions, the researchers hoped to identify and encourage some of the needed paradigm shifts.

The Research Design

In order to explore the identified research questions, the researchers sought the cooperation of a transit agency that had an ongoing marketing effort designed to increase ridership in an area experiencing air quality and traffic congestion problems. This was necessary to ensure that the sample population would have some knowledge of the environmental factors that provide a motivation to use public transit and the available public transit alternatives, even if they were not transit users. The researchers secured the assistance of a public transit property that was interested in the level of ridership on its bus routes connecting suburban residential areas with a major urban retail and business employment corridor. The agency is located in a major (top 10 in population) urban area that has well-documented air quality and traffic congestion problems.

Method

The following sections describe the survey methodology used in the study.

Survey Participants. A random sample was contacted by telephone (352 completed calls). Individuals employed in the area served by the transit property's buses were identified as the appropriate respondents. Because there is little motivation to use the local public transit service, more than 17,000 calls had to be made in order to identify qualified respondents. Each respondent answered questions during an interview of approximately eight minutes. Since commuters into the area come from any of four counties in the metro area surveyed, an effort was made to stratify the selection process to reflect the relative size of each county. Screening questions were used to ensure that respondents met the predetermined qualifications: age 18, full-time employee in the area of interest, and a resident of one of the four counties served by the transit property. The sample characteristics are identified in Table 1. In general, the sample characteristics indicate that those employed in the area are generally well-educated, middle- to upper-middle-income level, white-collar workers. Respondents tend to classify themselves as white/Caucasian; there are slightly more females than males, and they are approximately normally distributed in age. The demographic profile of the respondents appears consistent with the fact that the major employers in the area are upscale retail outlets and professional offices.

Survey Implementation. Survey respondents were randomly selected from a commercial computer-based telephone data system. The staff of the Florida State University Marketing Institute conducted the telephone interviews. All interviewers had extensive training and were supervised.

Survey Instrument. The questionnaire was developed specifically to assess current travel patterns, mode choice, and the potential impact of external events or attitudes toward travel behavior. The instrument was developed after consultation with the local transit property and a review of the existing research on attitudes toward alternative transportation modes.

Survey Processing. The telephone interviews were completed during a six-week period during the fall. The data were inspected and entered into computer readable files. Analysis was undertaken using SPSS 8.0 software.

Results

Five specific questions were investigated in this study:

- How important is the commuting decision to consumers?
- What are the best solutions to current transportation problems?
- What are the characteristics of existing home–work–home commute patterns?
- What would encourage the use of public transit?
- Which “businesses” should public transit agencies consider part of their mission?

Table 1
Telephone Survey Respondent Characteristics

Gender	*Frequency*	*Percentage*
Male	157	44.9
Female	193	55.1
Age	*Frequency*	*Percentage*
Under 30	62	17.8
30–34	58	16.6
35–39	65	18.6
40–49	99	28.4
50 and older	58	16.6
Refused	7	2.0
Race	*Frequency*	*Percentage*
White	281	81.7
African-American	50	14.5
Asian	3	0.9
Spanish or Hispanic	3	0.9
Other	7	2.0
Don't know	0	0.0
Refused	6	
Income	*Frequency*	*Percentage*
Less than $20,000	9	2.6
$20,000–$30,000	26	7.5
$30,001–$40,000	39	11.3
$40,001–$50,000	44	12.7
$50,001–$70,000	66	14.1
Over $70,000	111	32.1
Refused	51	
Education	*Frequency*	*Percentage*
Eleven years or less	1	0.3
Completed high school	61	17.6
Business or technical school	7	2.0
Some college	82	23.7
Completed college	139	40.2
Graduate or professional school	56	16.2
Occupation	*Frequency*	*Percentage*
Executive/Managerial/Professional	135	38.9
Administrative/Technical	60	17.3
Clerical/Secretarial	32	9.2
Manufacturing/Laborer/Operator	23	6.6
Sales/Service	51	14.7
Other	46	13.3
Refused	2	

Importance of Public Transit Issues

In order to develop a comprehensive understanding of the attitude of the area's commuters about the importance of public transit, respondents were asked to respond to several statements and questions. Their responses revealed the importance of transit service to the quality of life enjoyed by the area's commuters. Sixty-nine percent of the respondents rated the development of an effective public transit system as very important, even if they never used the service. Another 21 percent considered the issue important (Table 2). The rationale for this ranking by the respondents appears obvious. Nearly 77 percent suggested that traffic congestion has worsened in the area during the past year (Table 3). More than half (51.6%) rated their commute to work as more stressful than the other aspects of their workday (Table 4). Nearly 94 percent of the respondents agree that traffic congestion is a serious problem in the area (Table 5) and 88.7 percent agree that traffic congestion has a personal effect on their life (Table 6). Over 90 percent (91.7%) of those completing the survey also believe that the area's traffic congestion could be greatly reduced if some people cut back on their car trips (Table 7).

One obvious implication of these results is that transit properties might be well advised to make potential users aware of the benefits of using public transit. Marketing efforts (e.g., advertising messages) by transit organizations should reinforce the idea that having a public transit system is important and it should be used because using public transit reduces congestion and stress.

Table 2
Importance of Public Transit

Question: How important is it to develop public transportation in your community even if you never use the service?

Response	*Frequency*	*Percentage*
Very important	238	69.2
Somewhat important	71	20.6
Neither important nor unimportant	2	0.6
Somewhat unimportant	12	3.5
Very unimportant	21	6.1

Table 3
Traffic Congestion

Question: Generally, in the past year, traffic congestion in the area has:

Response	*Frequency*	*Percentage*
Gotten worse	259	76.9
Gotten better	11	3.3
Stayed about the same	64	18.9
Don't know	3	0.9

Table 4
Work Commute Stress

Question: Compared to other aspects of your workday, how stressful do you find your commute to work? (Please answer from 1–5 with 1 being much more stressful and 5 being much less stressful.)

Response		*Frequency*	*Percentage*
Much more stressful	1	89	25.5
	2	91	26.1
	3	88	25.2
	4	52	14.
Much less stressful	5	29	8.3

The link between single-occupancy vehicle (SOV) commutes and air quality is acknowledged as 83.5 percent of the respondents agreed that air pollution would be greatly reduced if some people cut back on their number of car trips (Table 8). In addition, 62.8 percent agreed that air pollution is a serious problem in the area (Table 9). However, less than half of the respondents (49.6%) believe they are personally affected by the area's poor air quality (Table 10).

Apparently, consumers have difficulty seeing the effects of poor air quality, probably because of the long-term nature of the impact. Thus, public transit marketers must make education a key tool in their advertising campaigns.

Solutions to the Area's Transportation Problems

Based on the survey results, three basic alternatives were identified: (1) build more highways, (2) rideshare programs, and (3) better public transit.

Table 5
Traffic Congestion–Seriousness of Problem

Question: Traffic congestion is a serious problem in the area.

Response	*Frequency*	*Percentage*
Strongly agree	227	65.0
Agree	101	28.9
Neutral	13	3.7
Disagree	7	2.0
Strongly disagree	1	0.3

Table 6
Personal Effect of Traffic Congestion

Question: I am personally affected by traffic congestion.

Response	*Frequency*	*Percentage*
Strongly agree	178	51.1
Agree	131	37.6
Neutral	19	5.5
Disagree	18	5.2
Strongly disagree	2	0.6

Table 7
Traffic Congestion Reduction and Car Trips

Question: Traffic congestion would be greatly reduced if some people cut back on how often they make car trips.

Response	*Frequency*	*Percentage*
Strongly agree	144	41.4
Agree	175	50.3
Neutral	14	4.0
Disagree	14	4.0
Strongly disagree	1	0.3

Table 8
Air Pollution Reduction

Question: Air pollution would be greatly reduced if some people cut back on how often they make car trips.

Response	*Frequency*	*Percentage*
Strongly agree	108	31.3
Agree	180	52.2
Neutral	31	9.0
Disagree	20	5.8
Strongly disagree	6	1.7

Table 9
Air Pollution Evaluation

Question: Air pollution is a serious problem in the area.

Response	*Frequency*	*Percentage*
Strongly agree	71	23.7
Agree	117	39.1
Neutral	32	10.7
Disagree	51	17.1
Strongly disagree	28	9.4

Table 10
Air Pollution's Effect on Me

Question: I am affected personally by air pollution.

Response	*Frequency*	*Percentage*
Strongly agree	42	12.7
Agree	122	36.9
Neutral	51	15.4
Disagree	91	27.5
Strongly disagree	25	7.6

Predictably, the most frequent response (33.8%) was that some combination of the three alternatives represented the best solution to the area's current transportation problems (Table 11). However, the most popular solution of the three was a better public transit system (27.7%). Building more highways was the least popular option (9.0%).

Table 11
Solutions for Transit Problems

Question: Which of the following would you say is the best solution to the area's current transportation problems? (Choose all that apply.)

Response	*Frequency*	*Percentage*
Build more highways	42	9.0
Rideshare programs	75	16.1
Better public transit	129	27.7
All of the above	157	33.8
No problems exist	2	.4
Not sure	5	1.1
Other	55	11.8

Table 12 summarizes the relationship between respondents' opinions regarding the area's air quality and traffic congestion and the best solution to the area's current transportation problems. Of the three primary options, building a better public transportation system is the most popular choice when air quality or traffic congestion is considered a serious problem or personally impacting. However, an even greater number of respondents feel the best solution involves some combination of the three options.

While the number calling for a combination strategy appears to suggest a preference for the auto as a means of commuting, this still represents a positive for the transit industry. Highway and rideshare programs are part of the old transportation paradigm. Replacing old transit systems with something better is a move toward a paradigm shift. While "better public transit" is a vague solution, it can be interpreted as a call for something new. It is a call the public transit industry needs to answer. However, before answers can be formulated, the problem needs to be understood. To that end, the researchers next examined the nature of the area's commutes.

Table 12
Comparison of Air and Traffic Opinions and Solutions to the Area's Transportation Problems (in percent)

Solution ——➤ *Opinion*	*Build Highways*	*Ride Together*	*Better Public Transit*	*All of These Options*	*There Are No Problems*	*Not Sure*	*Other*
Air pollution is serious	8.0%[a]	26.1%	39.4%	44.7%	0.0%	1.6%	17.6%
I'm affected by air pollution	9.8	26.2	41.5	40.2	0.0	0.6	12.1
Air pollution reduced by fewer trips	10.1	23.3	38.2	46.9	0.0	0.3	15.6
Traffic congestion is a problem	11.0	20.7	37.5	45.4	0.6	0.9	16.2
I'm personally affected by traffic congestion	12.3	22.0	36.9	45.0	0.3	1.3	16.5
Traffic reduced by fewer car trips	11.6	22.2	37.2	45.9	0.3	0.9	15.9
I can reduce my car trips	3.9	28.6	32.5	46.8	1.3	1.3	15.6

[a] Represents the percent of individuals who strongly agree or agree with the opinion who suggest that the appropriate solution is as noted. In this case, 8 percent of those who strongly agree or agree that air pollution is a serious problem in the area suggest that the best solution is building additional highways. Rows may sum to more than 100 percent because respondents were allowed to choose multiple solutions.

Characteristics of the Home-Work-Home Commute

Table 13 suggests that the vast majority of the area's commutes are made in SOVs, as 81.0 percent of the respondents drive alone to work five days a week. The mean commute time to work is 34.9 minutes (Table 14) and the reverse commute averages 37.6 minutes (Table 15). Most commuters travel directly to work (63.5% travel directly to work five or more days per week); however, only 29.9 percent return directly home after work a like number of times (Tables 16 and 17). In addition, 67.2 percent of the sample uses their car during the workday at least twice per week (Table 18). Thus, it is not surprising that only 21.9 percent of the respondents indicate that they are able to reduce the number of car trips made to work each week (Table 19).

These results point out three distinct factors that must be considered in the transit industry's strategic initiatives:

1. On average, over an hour a day is spent commuting to and from this area. This is a significant "cost" to commuters.

Table 13
Area Commute Patterns

Question: The next set of questions address how you get to work each day. Please indicate (on average) how many days per week you travel to work by the following means of transportation:

Number of Days	*Drive Alone*	*Carpool*	*Vanpool*	*Urban System*	*Walk*	*Bicycle*	*XXX*	*Other*
1	0.9	20.0	100	0	0	100	33.3	100
2	3.0	15.0	0	100	100	0	33.3	0
3	5.1	20.0	0	0	0	0	0	0
4	2.7	7.5	0	0	0	0	0	0
5	81.0	32.5	0	0	0	0	0	0
6	6.0	2.5	0	0	0	0	33.3	0
7	1.2	2.5	0	0	0	0	0	0
N	332	40	1	1	2	1	3	1
Mean	4.8	3.0	1.0	2.0	2.0	1.0	3.0	1.0

Table 14
Home-to-Work Commute Time

Question: About how long does the trip from home to work *usually take?*

Response	*Frequency*	*Percentage*
Less than 20 minutes	65	18.6
20–29 minutes	60	17.2
30–39 minutes	88	25.2
40–59 minutes	87	24.9
60 or more minutes	49	14.0
Mean = 34.9		

Table 15
Work-to-Home Commute Time

Question: About how long does the trip from work to home *usually take?*

Response	*Frequency*	*Percentage*
Less than 20 minutes	78	22.3
20–29 minutes	33	9.3
30–39 minutes	94	26.9
40–59 minutes	80	22.8
60 or more minutes	65	18.6
Mean = 37.6		

Table 16
Days per Week Making Nonstop Trip to Work

Question: In a typical week, how many days do you go directly to work withoutmaking any stops?

Response	*Frequency*	*Percentage*
0	35	10.0
1	8	2.3
2	14	4.0
3	23	6.6
4	47	13.4
5	212	60.6
6	11	3.1
Mean = 4.17		

Table 17
Days per Week Making Nonstop Trip Home from Work

Question: In a typical week, how many days do you return directly home from work without making any stops?

Response	*Frequency*	*Percentage*
0	37	10.7
1	22	6.3
2	30	8.6
3	72	20.7
4	82	23.6
5	99	28.5
6	5	1.4
Mean = 3.32		

Table 18
Nonwork Car Usage

Question: Not counting your trip to and from work, how many times, on average, do you use your car during the workday for things such as shopping, running errands, off-site business meetings, or lunch?

Response	*Frequency*	*Percentage*
Never	56	16.0
Once a week or less	59	16.9
2–4 times a week	101	28.9
Once a day	71	20.3
Twice a day	19	5.4
More than twice a day	44	12.6

Table 19
Ability to Reduce Work Commute

Question: I am able to reduce the number of car trips to work I make each week.

Response	*Frequency*	*Percentage*
Strongly agree	17	4.9
Agree	59	17.0
Neutral	32	9.2
Disagree	207	59.5
Strongly disagree	33	9.5

2. The reverse commute is more problematic for public transit operators. Strategies to accommodate multiple-task reverse commutes need to be a priority in the strategic planning initiatives of public transit agencies.
3. Most commuters make personal and work-related trips during the workday. To effectively compete, public transit must accommodate these trips.

In summary, these three factors suggest that commuting is time consuming and that reverse commutes (i.e., work–to–home) are multitask oriented. One motivation to use public transit might be the ability to make productive use of the time spent commuting. In area studies, over an hour a day could be added to the workday, leisure activities, or relaxation if public transit is utilized. The difficulty is overcoming the need for the flexibility provided by a car. Research can identify the most common tasks performed at lunch or on reverse commutes. Some transit properties have studied these tasks and are adding child care, dry cleaning, food, and workout facilities at selected stations.

Encouraging Alternative Forms of Transportation

Table 20 identifies the commute alternatives that respondents would consider using at least once a week, if they were available. The alternative most frequently identified as one that would be used, if available, was carpooling (52%), closely followed by rail service (50.3%). The bus system offered by the cooperating transit agency (suburban system bus in Table 20) was the third most frequently identified option (32.4%). Of these three, only rail service is not currently available in the area studied.

Table 20
Commute Alternatives

Question: If available, which of the following means of commuting would you consider using at least once per week? (Circle all that apply.)

Mode	*Frequency*	*Percent of Respondents*
Walk	95	27.0
Carpool	183	52.0
Vanpool	99	28.1
Suburban system bus	114	32.4
Bicycle	54	15.3
Urban system train	177	50.3
Urban system bus	110	31.3
Other	4	1.1
None	52	14.8

Only one in five respondents (20.3%) indicated that they could never use an alternative commuting option because of their job requirements or lifestyle (Table 21). This is also a positive for the industry. The most frequently identified incentive to use an alternative form of transportation was a guaranteed ride home (76.5%), followed closely by financial incentives (73.5%) (Table 22). More than two-thirds of the sample (67.2%) indicated that they would commute by transit more often if their employer offered a free or subsidized pass (Table 23). The implication of these findings for transit marketers are rather obvious: provide incentives to use public transit. Many transit properties, in fact, already have pursued such programs with major employers in their service areas.

Disincentives are also important and 85.1 percent of the respondents found it not difficult at all to find a convenient parking space every workday (Table 24). In fact, 92.3 percent parked in a lot or garage at their worksite (Table 25). In contrast to the door-to-door convenience of the SOV commute, for more than two-thirds of the sample (68.9%) the nearest bus stop to their residence is three or more blocks away (Table 26). In contrast, 70.6 percent have a stop within two blocks of their worksite (Table 27).

Table 21
Days Could Use a Commute Alternative (weekly)

Question: Given the requirements of your job and your lifestyle, how many days per week could you use the commute alternatives selected above?

Mode	*Frequency*	*Percent of Respondents*
0	61	20.3
1	22	7.3
2	43	14.3
3	56	18.6
4	10	3.3
5	102	33.9
6	4	1.3
7	3	1.0
Mean = 2.89		

Table 22
Reasons to Use a Commute Alternative

Question: Which of the following would encourage you to use alternative transportation in general more often to commute each day?

Reason	*Yes*	*No*	*N*
Parking fees	46.7	53.3	334
Financial incentives	73.5	26.2	340
More flexible work hours	53.8	46.2	340
Guaranteed ride home	76.5	23.5	344
Showers/lockers	28.2	71.8	326
Use of company vehicle	36.3	63.7	328
Frequent and direct bus service	59.8	40.2	336
Shopping and services	50.5	49.5	333
Other	1.1	98.9	4
None of the above	8.0	92.0	28

Table 23
Use of Commuter Transit If Free

Question: Would you commute by transit (bus or train) more often if your employer offered you a free or subsidized pass?

Mode	*Frequency*	*Percent of Respondents*
I commute by transit now		
My company offers it, but I don't use it	1	0.3
No, I would not change	98	28.2
I possibly would change to transit	136	39.2
I definitely would change to transit	97	28.0
Don't know	15	4.3

Businesses that Transit Agencies Should Consider Part of Their Mission

One obvious implication of the responses is that transit agencies need to be in the information business. Only about one out of four respondents (24.3%) received information on public transit options from their employer (Table 28). A basic tenant of marketing is that one must be "aware" of a product before they can purchase or use it. Internet access appears to be one viable option in the effort to increase awareness of public transit services as 55.8 percent of the respondents have Internet access at home (Table 29) and 63.6 percent have it at work (Table 30).

For transit marketers, any paradigm shift must account for the dynamic nature of consumer communications. Websites and email have rapidly emerged as preferred communication options. Information dissemination is key to

Table 24
Parking Difficulty

Question: How difficult is it to find a convenient parking space every workday that you drive?

Response	*Frequency*	*Percentage*
Very difficult	19	5.4
Somewhat difficult	28	8.0
Not at all difficult	297	85.1
Don't drive to work	5	1.4

Table 25
Work Parking Location

Question: Where do you usually park for work?

Response	*Frequency*	*Percentage*
Lot or garage at your worksite	323	92.3
Within three blocks of your worksite	23	6.6
Further than three blocks from your worksite	3	0.6
Don't drive to work	3	0.6

Table 26
Nearest Bus Stop–Residence

Question: Approximately how far is the nearest bus stop from your residence?

Response	*Frequency*	*Percentage*
One block or less	36	15.3
1–2 blocks	32	13.6
3 or more blocks	162	68.9
Don't know	5	2.1

Table 27
Nearest Bus Stop–Work

Question: Approximately how far is the nearest bus stop from your work?

Response	*Frequency*	*Percentage*
One block or less	127	47.7
1–2 blocks	61	22.9
3 or more blocks	78	29.3
Don't know	0	0.0

attracting and retaining customers in any industry. Not only can information technology become a key to building service awareness, innovative public transit managers must look to information technology as a way to extend their product before technology becomes a competitor. Telecommuting is increasingly popular. If transit does not embrace information technology, it may find itself at the wrong end of a competitive struggle. Can the daily commute be

Table 28
Transit Information Provided by Company

Question: Has your employer ever given you or your coworkers information on carpooling, vanpooling, or public transportation?

Response	*Frequency*	*Percentage*
Yes	83	24.3
No	255	74.6
Don't know	4	1.2

Table 29
Internet Access–Home

Question: Do you have access to the Internet at home?

Response	*Frequency*	*Percentage*
Yes	192	55.8
No	151	43.9
Don't know	1	0.3

Table 30
Internet Access–Work

Question: Do you have access to the Internet at work?

Response	*Frequency*	*Percentage*
Yes	218	63.6
No	125	36.4
Don't know	0	0.0

made more effective by providing access to technology? Some airports now have electronic service retailers who provide email, fax, word processing, and other electronic services. Airlines are also experimenting with such services. Could the bus or train of the future be equipped to provide similar services? Would this provide a sufficient motivation to attract and retain riders?

Another nontraditional option involves property development (Table 31). Transit property–based restaurants are identified by 88.1 percent of the respondents as a likely candidate for their patronage. Restaurants like TGI Fridays and Outback can now be found in facilities such as major league baseball parks and airport terminals that many thousands of individuals frequently visit. Public transit services have similar characteristics. Other facilities the study's respondents suggest for public transit centers include grocery stores (65.8%), convenience stores (64.1%), and bookstores (63.5%). Still other popular options include dry cleaners (52.0%) and exercise facilities (51.2%). A third group includes educational facilities (45.5%), office supply stores (42.3%), and video stores (39.4%). Child care comes in last at 21.5 percent.

The workday responsibilities and needs of transit users create the need for multiple-task trips and they currently represent a barrier to the use of public transit. Paying bills, eating lunch, and trips to the dry cleaners or grocery store often require off-property trips during breaks in the workday or on the way home. If banking and other services were available at a transit stop, would this also provide an incentive to use alternative transportation? Some transit properties have had success with day care, dry cleaning, and fast-food outlets. Are there other options that would remove such barriers to the use of public transit?

Table 31
Worksite Facility Usage

Question: If the following services were available within walking distance of your worksite, would you be likely to use any of the following before, after, or during your workday?

Facility	*Yes*	*No*	*Don't Know*
Bookstore	63.5	28.7	7.7
Convenience store	64.1	32.8	3.2
Educational facility	45.5	48.7	5.8
Grocery store	65.8	31.0	3.2
Restaurant/Eatery	88.1	10.7	1.2
Child care	21.5	75.6	2.9
Dry cleaners	52.0	45.1	2.9
Exercise facility	51.2	44.8	4.1
Office supply store	42.3	55.1	2.6
Video store	39.4	57.1	3.5

Is it possible for transit agencies to combine the electronic and property development options? Could electronic banking kiosks be provided in transit facilities? Electronic ordering of food and other products could be facilitated through software provided to frequent transit users as a benefit of their patronage. Items ordered could be delivered for pickup at designated transit stops.

Analysis and Interpretation

The crisis facing public transit agencies is both structurally and attitudinally based. The U.S. pattern of economic development and urban planning has generated urban sprawl and the family financial resources to support it. Households commonly have a vehicle for every family member able to drive. The number of individuals truly dependent on public transit for mobility has declined and the locations of jobs for such individuals often eliminate public transit as a practical alternative. Moreover, some public assistance programs now purchase cars for individuals.

Thus, it is a simple and well-established fact that most work commutes are now made in SOVs. More expensive gas has not reduced SOV commutes. Limits on spaces for parking and higher parking costs are unpopular options. Generating consumer dissatisfaction is seldom an effective long-term marketing strategy. Rather, the implication is that commuters need a positive incentive to motivate them to use public transit. Increasing the cost of alternatives through limited parking access or higher fees will not generate the customer satisfaction and loyalty needed to attract and retain customers.

Implications for Shifting Public Transit's Existing Market Paradigm

Benefit-based strategies should be a hallmark of the industry's paradigm shift. Information technologies, new services and amenities, and value-based pricing have the potential to enhance the market position of public transit.

Quality-of-Life Issues

What other options are available to transit agencies? Based on this study, it is evident that public transit does have options. Survey respondents are well educated and well paid, yet they expressed a willingness to use well-designed public transit services. They recognize traffic congestion as a problem, as they do air pollution. The link between the two is also acknowledged. The sampled commuters strongly indicate that reducing commutes is the solution to what are significant air quality problems. It is also apparent that the stress of commuting has an acknowledged impact on their quality of life. However, the respondents also suggest that the air quality issue does not affect them personally. The implications for transit marketers is that there is a need for efforts that:

- reinforce the link between the stress of commuting and one's quality of life;
- link traffic congestion, air quality, and life quality; and
- establish that air quality has a personal effect on commuters.

These relationships are captured in Figure 1.

Market Segmentation

The results summarized in Table 1 are indicative of the changing target markets for transit services. What is immediately apparent is the income and educational profile of the commuters within the area studied. Nearly one-third of the commuters sampled (32.1%) report an income of $70,000+. In contrast, only 2.6 percent have a household income of less than $20,000. Fully 56.4 percent have at least a college degree. Fifty-six percent (56.4%) are employed as either executives/managers/professionals or administrators/technicians. This area's commuters are generally using transit by choice, not out of necessity.

The implication is rather clear. If public transit agencies want to attract and retain such commuters, they cannot do so with cost-based, utilitarian services. High-profile consumers such as these commuters are interested in product benefits. To be attracted to public transit, they must see tangible benefits over their existing transit mode (normally an SOV). If public transit properties cannot provide something that their SOV does not, they will not become a transit rider.

What are their options? The transit property can provide a driver and a vehicle, or they can provide freedom from stress, better air quality for the commuter's family, convenient access to needed services, additional leisure or work time, and maybe even a little "fun." The challenge is to change their man-

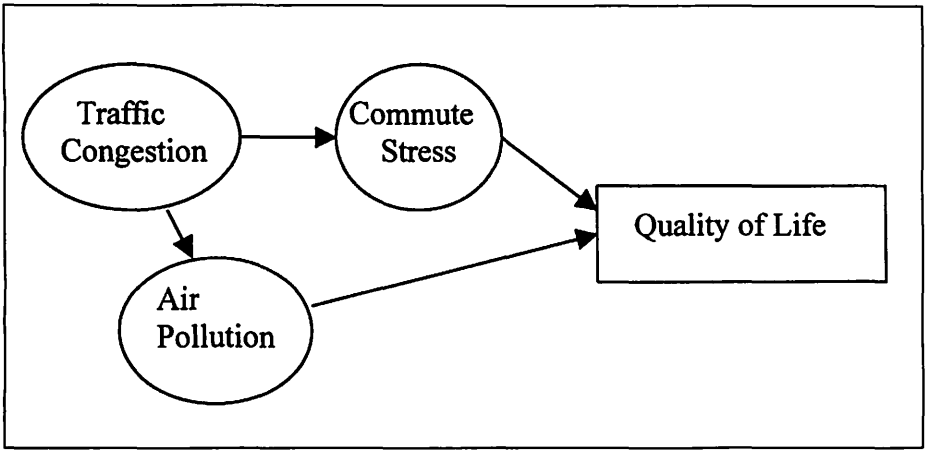

Figure 1. Quality-of-life issues

agement paradigm from an "operational" perspective to a more "customer-focused," market-based approach that embraces such market-driven strategies.

Multiple-Mode Options

The multiple-trip purposes revealed in the survey responses also call for a more comprehensive product offering. In Europe, the new public transit paradigm views a public transit property as a transportation facilitator rather than a transit provider. The facilitator agency provides not only the standard commute options, but also a neighborhood SOV should the rider need one. They also extend trip planning, and even car purchasing, assistance if required.

In the United States, at least one vanpooling operation is owned by a car rental firm. Why consider the two separate operations? A 4-passenger carpool may not be as efficient as a 9- or 11-passenger vanpool, but it is better than four SOVs. New management paradigms for the public transit industry must accommodate such trade-offs. Just as the freight-carrying portion of the transportation industry long ago discovered the benefits of multimodal solutions, commuter transit properties must accommodate similar needs. If a transit user drives his or her car to a station or stop, and then takes the bus or train, is it not a multimodal trip? Could a carpool, vanpool, taxi, or small bus make this system even more efficient? Diversified transit planning must become a cornerstone of the new transit paradigm.

Retail Property Development

Many of the country's transit properties have vast land holdings that lie in prime shopping areas. They also have a large number of "captured" customers. One needs only to go to Europe to find examples. In Paris, there is a multilevel underground shopping mall at one of the main downtown transit stations. All the shopping needs of commuters are satisfied in one location, all by well-known retail outlets.

In essence, public transit properties can become property managers or retail operators. Given their lack of experience in retail, the former appears to be the more prudent choice. Either way, a benefit is provided to transit riders, and a barrier to use is eliminated. An opportunity for additional operating capital is also inherent in this strategy.

Value-Generating Strategies

The core benefit that needs to be stressed through public transit's new management paradigm is value. Value is simply the ratio of product benefits to costs. The relevant costs include the dollar cost of the service, plus the time and effort required to use the service. Only in a few cases, in large metro areas such as New York City with high land values, can transit be sold on purely economic grounds. Even then, there is at least some debate as to whether the price of the parking space or the time spent finding it is the greatest cost.

The benefits provided by technology, facilitating multiple-mode trips, and retail shopping opportunities can increase the value of transit services to today's upscale commuter more than any price discount. Even "free" transit is often not used because of the barriers to its use; that is, it is simply not convenient to use. Reducing stress and improving air quality can add value to one's life. Commuters need to be educated about transit's role in this value-enhancing process.

Conclusions

Public transit managers have a unique opportunity to redefine their industry. If they fail to do so, all indications are that its market share will continue its decline and the industry crisis will slowly become a catastrophe. The industry simply has not kept pace with changes in the marketplace. Cars continue to grow more luxurious; public transit services do not. Public transit continues an emphasis on cost control and abatement when many customers are searching for comfort and convenience.

Currently, public transit is not a good fit with upscale markets such as the one investigated in this study. The markets have moved; the train and bus lines have not. Fewer and fewer U.S. consumers are driven to use public transportation by necessity. New-millennium commuters generally want value-added services, yet transit properties continue to stress low prices and discounts. Most consumers have a car, and it is considered a sunk cost. The only variable cost of note is gas. Public transit properties cannot operate more efficiently than a car in the mind of the car owner who has to make a payment whether he or she drives or rides the train or bus.

However, transit does have benefits unavailable to SOVs. The commuter does not have to drive. The commuter can work or relax, and does not have to worry about bad drivers. He or she can read or talk on their cellular phone with no fear of an accident. They might even find someone interesting with whom to interact. The stress of commuting can be reduced, and air quality enhanced. Is the value such benefits contribute to one's quality of life sufficient to motivate a shift from the SOV to public transit? It is a question that deserves the attention of transit managers.

No matter the perceived benefit, the major point is that public transit organizations must find ways to increase the value of their services. The current study suggests several courses of action. Others will come to mind. Nevertheless, the key component in public transit's paradigm shift must be the exchange of the cost-minimization approach to strategic decision making, to one of benefit maximization. Otherwise the industry will continue to lose market share. The new-millennium transit rider searches for value. The key for public transit properties in their efforts to attract and retain riders is to create services that have sufficient value to motivate consumers to leave their SOVs. Public transit's marketing strategies must originate with the needs and wants of consumers, not with the needs and wants of operations personnel.

To deny the need for a paradigm shift is to ignore the reality of the new-millennium marketplace. Recently, the International Taxi and Livery Association sponsored its first marketing seminar. Already, these private sector alternative transportation providers are diversifying their services in response to consumer demands. Where there once were taxis, today these firms operate taxis, executive sedans, and limos—different products performing essentially the same function, but for different market segments. To these services, many taxi operators have added airport shuttles and executive coaches. The really innovative operators now have contracts to provide concierge services in hotels and operate destination-management companies. They can literally book your flight and lodging, transport you from the airport to your hotel whether you are an individual or a group in the thousands, arrange theme parties and transport you to them, and then get you back to the airport for your flight home. And, while you are in town, if you'd like to check with the concierge, a special dinner can be arranged for you and yours along with a ride to the restaurant in one of their taxis, executive sedans, or limos! Is this a successful paradigm shift? You had better believe it is!

Endnote

1. The product life cycle (PLC) suggests that all products, both goods and services, go through a process that begins with their introduction to the market. The PLC is comprised of four basic stages: introduction, growth, maturity, and decline. The maturity stage is often broken into two separate stages—early maturity and late maturity.

References

Daft, Richard, Robert Lengel, and Glen Perdue. April 1998. Creating a new future for public transportation: TCRP's strategic road map. *Results Digest* 24, Washington, DC: Transit Cooperative Research.

Kotler, Phillip. 1997. *Marketing management: Analysis, planning, implementation, and control.* Upper Saddle River, NJ: Prentice Hall.

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Transit Station Area Land Use/ Site Assessment with Multiple Criteria: An Integrated GIS-Expert System Prototype

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Abstract

This article is intended to assist decision-makers confronted with the problem of determining the suitability of a site with a proposed light rail transit (LRT) stop as a transit supportive (re)development by exploring a prototype, integrated Geographic Information System (GIS) and decision-support system. An inclusive concept of a hierarchy is presented in which the multiple, diverse dimensions of the land-use/site assessment problem—from goal, criteria, to alternatives—can be embedded in deciding suitability of a site as a transit-supportive development.

Framed as a multicriteria procedure, and integrated with a GIS, the decision-support system provides the flexibility to account not only for the configurational or physical features of the built environment and the patterns of growth (or decline) of the population and employment in the region, but also the socioeconomic, demographic, and trip-making characteristics of the targeted population. The joint effects of the population (demand) characteristics and the features of the built environment of land use/trans-

portation (supply) are reflected in the scores of the site assessment. Furthermore, the prototype facilitates decision making by deriving the relative importance of the multiple "supply" and "demand" factors strategically and adaptively vis-a-vis the site-specific constraints and opportunities. Finally, criteria-weighted land-use suitability scores are computed and displayed to indicate the suitability of the site as a transit-supportive development. The multicriteria part of this prototype is implemented with a C++ program as an interactive, expert decision-support system integrated with a GIS.

Introduction

Spatial systems analysis and the planning of land use and transportation have been increasingly aided by GIS. GIS-based approaches surmount the limitation of the locational or allocational models (e.g., Urban Transportation Modeling System or standard urban simulation models) by providing physical or configurational features of the built environment as spatial data used in the analysis of land use and transportation. The configuration and "grain" of land use, the physical form or layout of the road network (e.g., grid versus curvilinear), street width, block length, continuity and compatibility of the circulation or movement systems—both vehicular and pedestrian—open space organization, building setbacks, layout of streets, parking areas, and sidewalks are among the factors considered in the suitability of a transit-oriented development (TOD) site (see also Calthorpe 1993; Ewing et al. 1997; Bernick and Cervero 1997). Consideration of land use and movement (vehicular and pedestrian) as systems with both functional and spatial (physical) properties are facilitated by GIS (see also Wegener 1998; Spiekermann and Wegener 1998).

The recent use of simulation models in combination with GIS is a new direction in analyzing the joint effects of land use and transportation, both highway and transit (e.g., see Landis and Zhang 1998). The facility to address the joint effects of land-use and transportation improvements at a development site is a strength of a combined GIS-simulation approach. The reliance on previous, historical patterns encounters a limitation of prediction with simulation methods (regression) in the absence of precedence or with structural transformation.

A plausible alternative to deductive, statistical simulation techniques are inductive, multicriteria methods. The Analytic Hierarchy Process (AHP) is one multicriteria method (Saaty 1987, 1996) that is increasingly used in conjunction with a GIS. Combined multicriteria-GIS methods with AHP are used diversely, ranging from evaluation of group decision making and route selection to the site-suitability evaluation of investment decisions and, most recently, in TOD site suitability (Jankowski and Richard 1994; Malczewski 1996; Lin et al. 1997; Banai 1993, 1998). The increasing popularity of AHP is attributed to its methodological flexibility in situations involving factor diversity, mixed-tangible and intangible criteria, uncertainty, and limited information (Banai 1989). Above all, it allows for a process of interpreting both tangible and intangible data directly and inductively—rather than inferring indirectly and deductively—while providing a robust scientific framework to gauge the consistency and efficacy of the interpretation (see Saaty 1986, 1996).

In this article AHP is integrated seamlessly with a commonly used GIS software (ArcView, ESRI, Inc., Redlands, California), and developed as a prototype GIS-Expert System to aid transit station area land use/site assessment. The multicriteria part of this prototype is implemented with a C++ program as an interactive, expert decision-support system, which is integrated with a GIS. The hierarchical structure of AHP is used as an approach to a transit station area site assessment. The aim of this approach is to account not only for the configurational or physical features of the built environment ("supply"), which are conducive to transit use, but also the socioeconomic and trip-making characteristics of the targeted population ("demand") of transit users. The joint effects of the population and the built environment of land use/transportation are reflected in the site assessment scores of the transit station area. This concept is in contrast to or supplements previous ones in which characteristically only the supply side of TODs is considered with multiple criteria or guidelines (e.g., Calthorpe 1993), however, with the demand side treated exogenously (as a given).

An Integrated GIS-Expert System Prototype for Transit Station Area Land Use/Site Assessment

The AHP is a rational method in which the analytic and synthetic operations are performed in a number of distinct steps. First, and most important, the structural property of AHP (hierarchy) should be used to frame the problem. In general, the hierarchy levels range from the abstract to concrete elements; that is, from goals, strategies, actions, to decisions, choices, alternatives, and outcomes.

In a typical AHP hierarchy, the goal, criteria, subcriteria (if any), and alternatives are represented as various factors in distinct levels in a descending order. The factors at each lower level are compared (pairwise) with respect to the factors at each higher level of the hierarchy. First, the relative importance of the criteria (for goal) is determined, followed next by the importance of subcriteria (for criteria), and finally by the relative importance of the alternatives (for subcriteria), which are represented at the lowest level of the hierarchy. Once the relative weights of the factors at all the levels of the hierarchy are determined, a weighted summation procedure is used in which the scores of the alternatives as aggregate (overall) weights of all the factors are given. A hierarchy for transit-oriented land-use suitability is shown in Figure 1.

At the kernel of AHP is a systematic, analytic procedure for determining the relative importance of factors through their paired comparisons. Homogenous factors are compared in reciprocal matrices by using this AHP scale of absolute numbers (1–9):

1 = Equal importance
3 = Moderate importance of one over another
5 = Essential or strong importance
7 = Very strong importance
9 = Extreme importance
2, 4, 6, and 8 = As intermediate values between two adjacent judgments

An example of such a reciprocal matrix ($a_{ji}=1/a_{ij}$) from the suitability criteria used in the next section is:

$$A = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \end{array} \begin{array}{c} \begin{array}{ccc} A_1 & A_2 & A_3 \end{array} \\ \begin{bmatrix} 1 & 3 & 5 \\ 1/3 & 1 & 3 \\ 1/5 & 1/3 & 1 \end{bmatrix} \end{array}$$

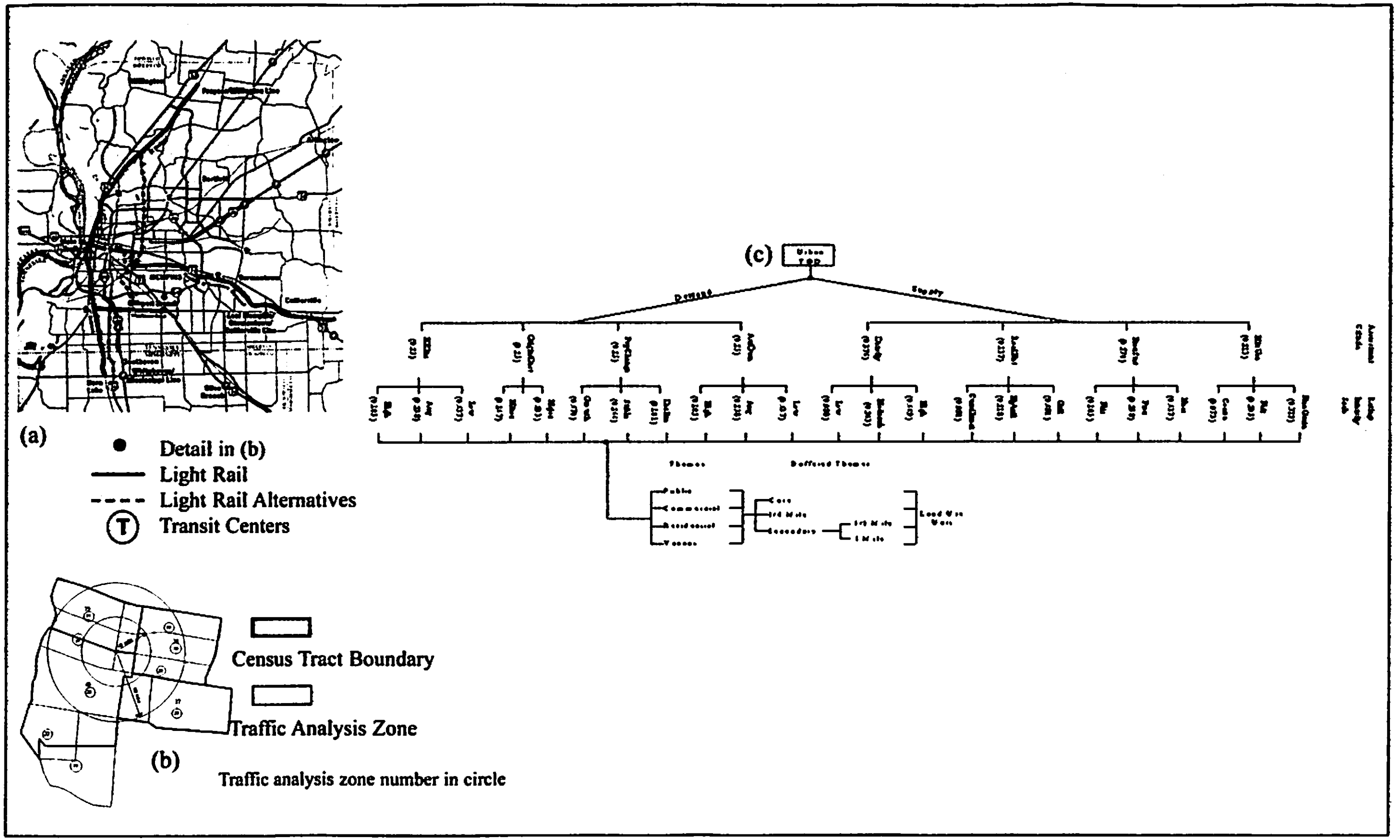


Figure 1. (a) Planned metropolitan region LRT lines (adapted from Memphis Area Transit Plan 1997); (b) station area focus; (c) a hierarchy for TOD land-use suitability

The rows and columns of this matrix are identically labeled by a set of factors A_1, A_2, A_3; thus, all the diagonal elements are 1 ($a_{ii} = 1$). Various methods, from the simple to more elaborate, may be used to compute the relative weight or importance of factors. The robust method of estimation in AHP, however, is the eigenvector solution (see Saaty 1996), which derives the relative weights of the factors on a ratio scale (0–1).

In the process of the paired comparison of factors or elements, the consistency of judgments is gauged.[1] An upper limit of 10 percent is considered a good measure of consistency (Saaty 1980). When exceeded, the estimates of the relative weights may be revised to improve consistency. Thus, consistency is gauged, particularly when violated in multicriteria evaluation in the face of limited information, data imperfection, uncertainty, and factor diversity.

The paired comparison method as an approach to relative measurement is particularly desirable when relative merit is all that can be expected, in the absence of standards. However, when certain desirable thresholds, if not fixed standards, exist, alternatives may be rated by means of absolute measurement. A rating intensity scale is developed and then used to rate alternatives, denoted in this study by land-use units. Both relative and absolute measurements are accommodated in the prototype presented here. The AHP is implemented with a C program and integrated with ArcView GIS.

An Application Example of the Integrated GIS-Expert System Prototype

A recently planned LRT station to be located in the medical district of Memphis, Tennessee, is the focus of suitability analysis of station area land uses (Figure 1a). This site is a major employment center in the metropolitan region. The area provides housing, ranging in both mix and density. An assessment of the suitability of this site as a TOD with respect to the station area land uses is of interest here.

The land-use suitability problem is framed hierarchically (Figure 1c). The assessment criteria, distinguished by supply and demand factors, the subcriteria (used for the ratings of the land uses), and the land-use units, comprise the levels of this hierarchy. The land-use units are mapped thematically (public, commercial, residential, and vacant) and buffered (GIS) by various distance from the LRT station. (For an elaboration of the significance of such a land-use classification, see Calthorpe 1993.) Tax assessor GIS parcel data (1998) provided the principal source of information for land-use classification. The differentiation of distance from the station (from ¼, ½, to 1 mile) aims to capture the corresponding effects on the suitability scores of land-use units. In addition, the aggregate scores of land-use units expressed proportionally (0 to 100%) indicate the potential suitability of this site compared to desirable threshold(s) for a TOD.

The assessment criteria on the demand side include four factors: (1) auto ownership (AutOwn), (2) population change (PopChange), (3) trip origin-destination (Origin/Dest), and (4) household income (HHInc). These factors are used as a measure of socioeconomic, demographic, trip-making, site-specific characteristics of the targeted population. Census tract and block (GIS) data (1990) and trip origin-destination data by traffic analysis zones (MINUTP) provide information for the site ratings (see also Figure 1b). The ratings intensity scales of the criteria are shown in Table 1.

For example, consider population change (differentiated by decline, stable, and growth) as a measure of site suitability. The ratings intensity scale is determined by three paired comparisons. The following assumptions are used: A site with both stability and growth in population is considered as moderately more important (3) and as strongly more important (5), respectively, than one with a decline in population. Also, a site with growth in population is given a nearly stronger weight (4) than one with a stable population. The relative weights are shown in the last column of the table. The Origin/Dest criterion assesses this site as a major activity (medical) center—an indicator of (employment) density on the demand side. Density (residential) is considered as well on the supply side. The relative weights of the subcriteria for the remaining, demand-side factors are similarly determined, with the assumptions of the paired comparisons indicated by AHP numerical scale (1 through 9).

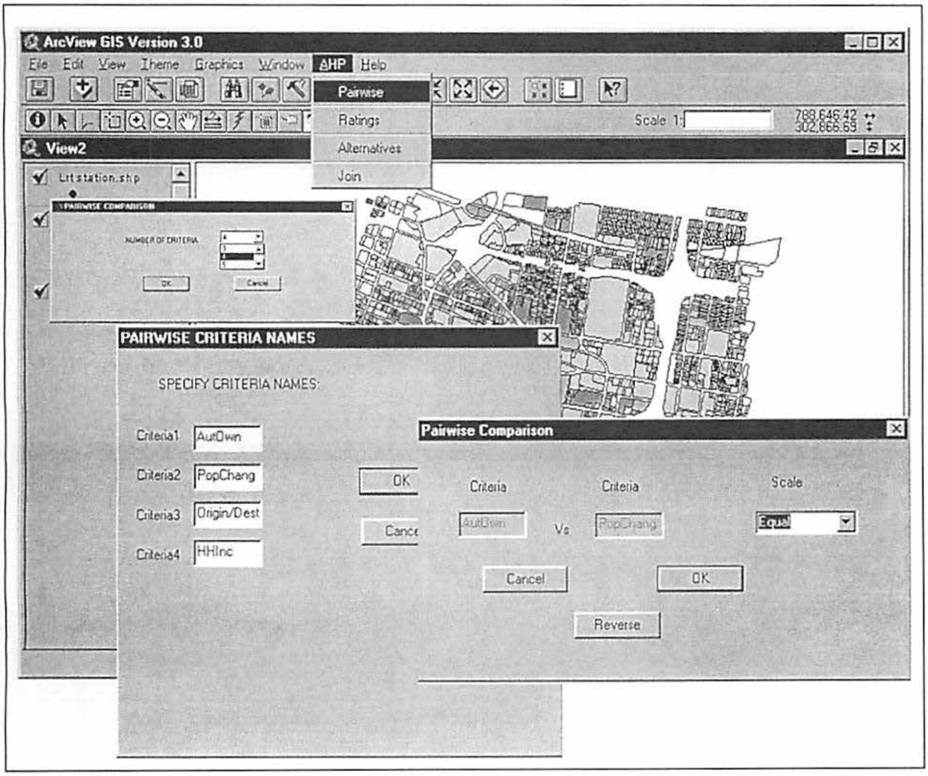
The assessment criteria on the demand side are considered equally important in this illustration (Figure 2). However, by means of paired comparisons,

Table 1
Deriving Ratings Intensity Scales for Demand-Side Factors

AutOwn	*Low*	*Average*	*High*	*Weight*	*PopChange*	*Decline*	*Stable*	*Growth*	*Weight*
Low	1	3	5	0.637	Decline	1	1/3	1/5	0.100
Average	1/3	1	3	0.258	Stable	3	1	1/4	0.226
High	1/5	1/3	1	0.105	Growth	5	4	1	0.674
HHInc	*Low*	*Average*	*High*	*Weight*	*Origin/Dest*	*Major*	*Minor*		*Weight*
Low	1	3	5	0.637	Major	1	5		0.833
Average	1/3	1	3	0.258	Minor	1/5	1		0.167
High	1/5	1/3	1	0.105					

the relative importance of the criteria can be derived. For example, the assessment criteria on the supply side vary in relative importance. These include road network (RoadNet), land-use mix (MixUse), proximity to LRT station (ProxStat), and housing density (Density) in ascending priority order (Figure 1c). For a discussion of these criteria as well as the significance of their relative weights, see Banai (1998). Once the relative importance of the criteria and the ratings intensity scales are determined, the alternatives expressed by land-use units are assessed. Figure 3 presents examples in which school and housing are assessed with both the supply- and demand-side criteria.

The suitability scores that reflect the effects of supply and demand criteria factors jointly are shown in Figure 4. In aggregate, the three land-use classes indicate a high suitability, with the highest score—public land use—at the critical quarter-mile-zone distance from the station. Commercial and residential uses score proportionately to public land use, suggesting the potential functional significance of this zone as a "balanced" transit-oriented site. The public land-use scores decline with distance from the LRT station. However, their relative weights indicate the significance of public land use even in zones beyond the quarter-mile, in what Calthorpe (1993) calls "secondary areas" of a TOD. The site examined here has initially met the planning criteria for station spacing and location within a major activity center. This site meets the criteria for a TOD as well, as the outcome of this preliminary analysis suggests. If stations in locations along the vari-



SPECIFY CRITERIA NAMES:

Criteria1 AutOwn
Criteria2 PopChang
Criteria3 Origin/Dest
Criteria4 HHInc

Criteria		Criteria	Scale
AutOwn	Vs	PopChang	Equal

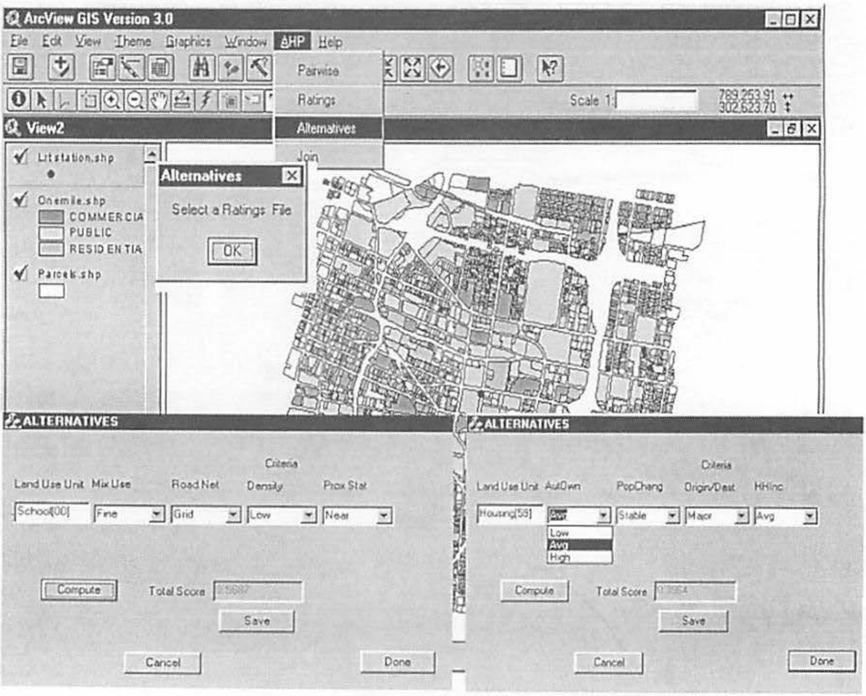
Figure 2. Submenus of AHP in ArcView GIS with examples of dialog boxes for deriving weights of the criteria and ratings intensity scales used in evaluating land-use units

ous planned LRT lines (Figure 1a) are similarly scrutinized, they could lend further credence to the planning criteria for route alignment and station spacing, with the indication of whether a station area's land uses are supportive of employment and shopping activities or of places in which to live, or both.

Land-use suitability scores are presented in aggregate (Figure 4). As shown in the dialog box in Figure 3, however, finer classification, as well as evaluation at the parcel level is accommodated by the integrated GIS-Expert System prototype.

A GIS-Expert System Integration

C++ is a general-purpose programming language that provides flexible and efficient facilities for defining new constructs specific to an application



Land Use Unit: School[00]
Mix Use: Fine
Road Net: Grid
Density: Low
Prox Stat: Near

Land Use Unit: Housing[59]
AutOwn: Avg
PopChang: Stable
Origin/Dest: Major
HHInc: Avg

Figure 3. Use of the Alternatives submenu of AHP to assess land-use units

domain (Strostrup 1997). It is widely used for application development. C++ provides powerful support with libraries and documentation for implementing the AHP. Some flavors of C++, such as Microsoft Visual C++ version 6.0, provide support for Windows programming.[2]

Since C++ is an object-oriented programming language similar to ArcView GIS (i.e., with Avenue scripts, ERS 1998), it provides an effective coupling of AHP with GIS in a single package. Once the user interacts with the AHP, the results can be stored, updated, and retrieved in a GIS. The implementation of AHP is carried out using Microsoft Visual C++ version 6.0 on Windows NT 4.0.

Software Architecture

ArcView GIS provides the driver software that invokes the user interface written in C++ (Figure 5). AHP is created as a basic menu in ArcView (ESRI,

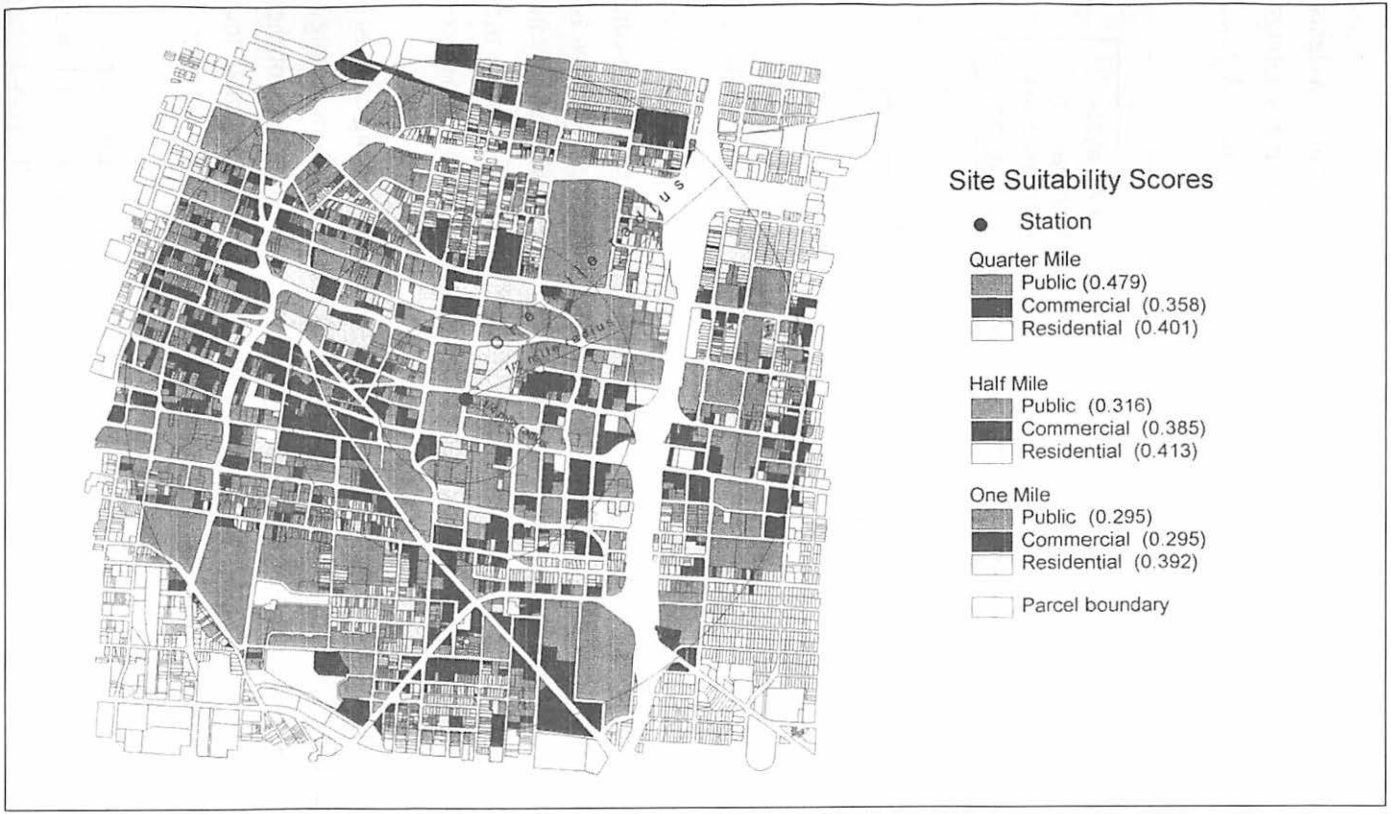


Figure 4. Land-use suitability ratings for an urban TOD by distance from LRT station (composite scores with supply and demand criteria)

version 3.0). The submenus of the AHP include Pairwise Comparison, Ratings, Alternatives, and Join. These menus help the user determine relative weights of the suitability factors, relative importance of subfactors using a ratings intensity scale, and the total suitability score for a land-use unit. A brief overview of the AHP submenus is presented below.

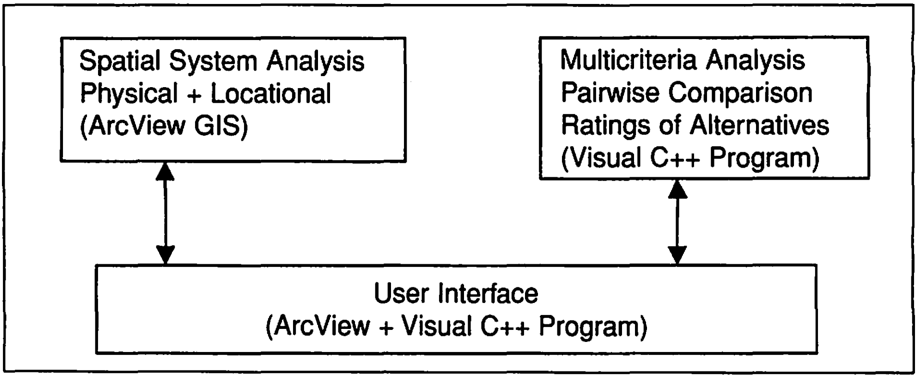


Figure 5. Software architecture

Pairwise Comparison. A new dialog box is created with a drop-down list box. On selecting the OK button, a "child" dialog window is created with edit boxes in which the user can specify the criteria names. Once the OK button is pressed, a series of pairwise comparison dialog boxes appears sequentially in which the user can compare one criterion with another. Finally, the Consistency Index is shown. The user can either save the pairwise comparison or discard the changes depending on the Consistency Index.

Ratings. A new dialog box appears with an option of selecting an existing Ratings file or creating New Ratings. If the user requests a New Ratings scale, the steps in the pairwise comparison are repeated for subfactors of the criteria shown. If the user selects an existing Ratings file, a summary of all the factors and weights of their subfactors is shown. Again, the user has the option of saving the Ratings carried out or discarding the changes.

Alternatives. In order for the user to access the Alternatives option, Ratings must have been carried out first and the results must be stored in a Ratings file. The Ratings file must be provided to compute Alternatives.

Join. The Join script provides a file dialog box in which the user can select the Alternatives file. Once the user selects the file, the Avenue script automatically updates the tables in GIS with the weights of the alternatives obtained from the previous step. These features are shown in Figure 6.

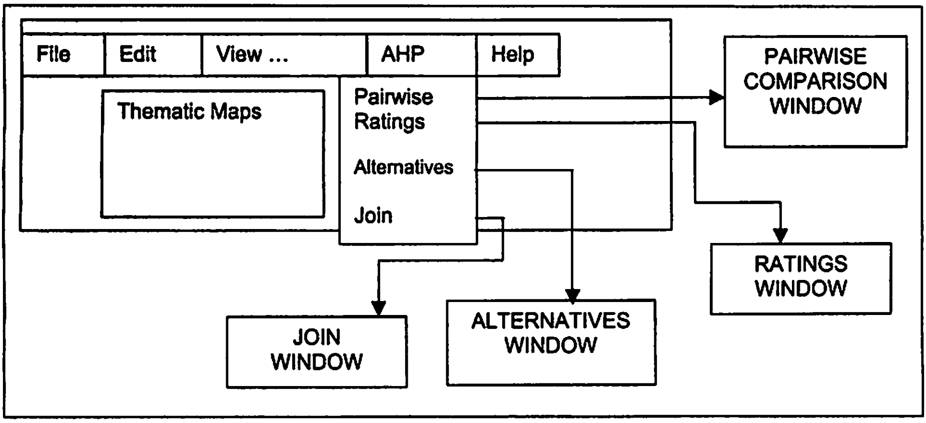


Figure 6. Abstract navigation features

Conclusions

Standard urban simulation models and statistical techniques provide greater facility to cope with the spatial/locational features of land-use and transportation systems than their physical/configurational features. Recent integration of locational or allocational models with GIS is a step in the direction of greater accountability to site- rather than zonal-level impacts of land-use and transportation systems. The site-specific physical/configurational features of land-use/transportation systems, however, defy conventional methods of analysis and evaluation. Configurational features of the built environment—land use, open space organization, street layout and the like—require methods that facilitate analysis and synthesis of form and function, empirical observation, and policy prescription. The integration of AHP as a multicriteria method with GIS offers the ability to interpret site-specific, sociospatial data directly and inductively, rather than to infer indirectly and deductively.

The AHP method supports an inductive-reasoning logic to consider the particulars specific to a site, city, or region in the light of general concepts, principles, and criteria for a TOD, station siting, or route alignment. The method aids decision-makers in deriving or modifying the weights of the criteria to reflect the conditions specific to a locality. The method is synthetic; that is, it allows for observation, empirical evidence, experience, and interpretation in problem framing and decision making. For example, the criteria for site suitability can be based not only on the (empirical) observation of areas with population growth (or decline), but also on the interpretation of their (transit-induced) economic development potential as well as the experience of growth management and regional policy. Similarly, the availability of parking, multimodal connectivity, land prices, and distance to major trip attractions can be explicitly scrutinized as criteria (or subcriteria) in site-suitability analysis. The procedure suggested in this article, however, remains the same in deference to the criteria used in a site-specific problem formulation.

The integrated GIS-Expert System prototype described here illustrates the use of the structural property of AHP to account for both the supply and demand factors as multiple criteria for a transit station area land-use/site assessment. This approach is in contrast to "checklist" methods or guidelines commonly used to assess desirable supply-side features of TODs. However, combined with the demand-side factors, they provide criteria for further site-specific assessment of their relative importance as well as ratings of transit area land use by AHP. Finally, both the popularity of AHP as a multicriteria method and the (ArcView) GIS are considered as factors with equal importance to further application, dissemination, and research and development of the integrated GIS-Expert System prototype.

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Endnotes

1. Consider an example of a perfectly consistent set of preferences: an apple (*i*) is moderately (3) preferred to an orange (*j*), which is twice as much preferred to a grapefruit (*k*); the apple is strongly (6) preferred to grapefruit. Denote the relative weights

by a_{ij}, a_{jk}, a_{ik}, respectively. With consistency $a_{ij} . a_{jk} = a_{jk}$, and the largest characteristic value of $A=(a_{ij})$, the matix of ratio estimates, denoted by λmax equals n, the number of factors or elements compared in A. However, with inconsistency $(a_{ij} . a_{jk} \neq a_{ik})$, $\lambda_{\max} > n$. In general, then, $\lambda_{\max} \geq n$ (Saaty 1980), a property that is used to obtain a measure of deviation from consistency, with an index CI:

$$CI = (\lambda_{\max} - n)/(n - 1)$$

The value of CI is compared with its average value for a randomly generated reciprocal matrix of the same size as A. The comparison indicates whether the paired comparisons are performed consistently or randomly.

2. Microsoft Visual C++ provides built-in classes in the form of Microsoft Foundation Classes (MFCs) like CDialog and CfileDialog, which facilitate user interface with timely development of new applications (Microsoft Visual C++, version 6.0).

References

Banai, K. R. 1989. A new method for site-suitability analysis: The Analytic Hierarchy Process. *Environmental Management* 13: 685–693.

Banai, R. 1998. Transit-oriented development suitability analysis by the Analytic Hierarchy Process and a Geographic Information System: A prototype procedure. *Journal of Public Transportation* 2 (1): 43–65.

Banai, R. 1993. Fuzziness in Geographical Information Systems: Contributions from the Analytic Hierarchy Process. *International Journal of Geographic Information Systems* 7 (4): 315–329.

Bernick, M., and R. Cervero. 1997. *Transit villages in the 21st century*. New York: McGraw-Hill.

Calthorpe, P. 1993. *The next American metropolis*. New York: Princeton Architectural Press.

ESRI. 1998. Avenue, Customization, and Application Development for ArcView, Redlands, CA.

Ewing, R., B. Mackey, and B. Sewell. 1997. Transit-oriented development in Florida. *Land Development* 10 (2): 31–35.

Jankowski, P., and L. Richard. 1994. Integration of GIS-based suitability analysis and multicriteria evaluating in a spatial decision-support system for route selection. *Environment and Planning B* 21: 323–340.

Landis, J., and M. Zhang. 1998. The second generation of the California urban futures model: Parts I and II. *Environment and Planning B* 25: 795–824; 30: 657–666.

Lin, H., Q. Wan, X. Li, U. Chen, and Y. Kong. 1997. GIS-based multicriteria evaluation for investment environment. *Environment and Planning B: Planning and Design* 24: 403–414.

Malczewski, J. 1996. A GIS-based approach to multiple criteria group decision making. *International Journal of Geographical Information Systems* 10 (8): 955–971.

Saaty R. W. 1987. The Analytic Hierarchy Process—What it is and how it is used. *Mathematical Modeling* 9: 161–176.

Saaty, T. L. 1996. *Multicriteria decision making: The Analytic Hierarchy Process.* Pittsburgh: RWS Publications.

Saaty, T. L. 1986. Axiomatic foundation of the Analytic Hierarchy Process. *Management Science* 32 (7): 841–855.

Saaty, T. L. 1980. *The Analytic Hierarchy Process.* New York: McGraw-Hill.

Spiekermann, K., and M. Wegener. 1998. Freedom from the tyranny of zones. In *Spatial models and GIS: New potential and new models.* A. S. Fotheringham and M. Wegener, eds. London: Taylor and Francis.

Strostrup, B. 1997. *The C++ programming language*, 3rd ed. Addison-Wesley Publishing Company.

Wegener, M. Anniversary Issue 1998. GIS and spatial planning. *Environment and Planning B: Planning and Design*: 48–52.

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Reading between the Regulations: Parking Requirements, Planners' Perspectives, and Transit

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Abstract

This article reports on local planers' perspectives on metropolitan parking requirements. Workplace parking requirements, which are often in excess of demand, influence parking pricing and urban form. In turn, these affect transit demand and transit service potentials. These connections have led researchers and policy-makers to call for changes, but the perspectives of planners who create the parking requirements are not well understood. Using southern California cities as a study area, a telephone survey revealed that most parking requirements are driven by concerns about traffic mitigation, spillover parking, and risk avoidance. These factors push parking requirements in the direction of oversupply. The article proposes methods to reduce the risk of changing parking requirements and develops a typology of approaches for change. Transit agencies will benefit if they play a role in reforming local parking requirements.

Introduction

This research provides information on planners' perspectives on local parking requirements. It is intended to help transit agencies and regional authorities work with local jurisdictions to develop transit-supportive parking requirements. Minimum parking requirements for workplaces, taken here as office, manufacturing, warehouse, and medical buildings, have been a formula-driven part of standard planning and zoning practice, largely disconnected from broader policy concerns. Parking is supplied according to standard ratios established in zoning ordinances and guidelines of the development industry. From a local perspective, a "good" project provides a generous supply of parking, great enough to meet any foreseeable peak demand, and it provides parking at no direct cost to tenants or workers. These circumstances create significant challenges for transit, because they are incentives for automobile commuting. Excess parking supply generally precludes parking pricing, and low-density development patterns make transit service more expensive to provide and less convenient.

This typical approach to workplace parking has been challenged in the last decade. Researchers find that the price of parking is positively related to transit use (Gillen 1977; Willson and Shoup 1990; Willson 1992a; Strathman and Dueker 1996; Willson 1997). The relationship between parking price and travel demand is robust and consistent. For example, Willson (1992a) found a cross elasticity of demand for transit with respect to a $3 parking charge to be +0.41. Researchers also find that typical minimum parking requirements exceed measured levels as well as peak utilization levels reported in publications such as the Institute of Transportation Engineer's (ITE's) *Parking Generation Handbook* (Willson 1992b and 1995; Shoup 1995; Regional Transportation Authority 1998).

Parking supply policy, then, is an attractive tool for policy-makers concerned with transit, traffic congestion, urban form, and environmental quality (see, for example, Committee for Study on Urban Transportation Congestion Pricing 1994). Federal "planning factors" support the development of parking strategies (Shaw 1997); significantly, more than half of 71 regional plans reviewed in that research address parking. Many of those plans call for parking charges, parking cash-out, or reductions in parking requirements.

This activity suggests strong interest in the reform of parking standards. Yet parking requirements are the domain of the local governments and are subject to their concerns. The process of reforming parking requirements begins with local zoning ordinances, real planners, and real problems. It involves many stakeholders, including planners, the development community, residents, employers, and other government agencies. For the most part, transit agencies have not been involved. This research focuses on planners because they draft the ordinances, they direct attention to problems and opportunities, and they know most about the stakeholder perspectives. Research on planning implementation shows that the political commitment of local government staff has an important bearing on the success of state mandates (Berke and French 1994). Local planners' attitudes, therefore, are an appropriate starting point for understanding local perspectives on policy (see Baldassare et al. 1995).

Methodology

This research provides survey information about workplace parking and planners' attitudes. Southern California is studied because of its size, the variety of city characteristics, and its role in influencing nationwide trends. Despite a reputation for auto dependency, the region has a long history of travel-demand management mandates and significant transit development. Mildner et al. (1997) create a scoring system to indicate the degree to which metro areas' parking policies support transit. They place the Los Angeles metro in the middle of a group of 20 metro areas, which suggests this study provides fairly typical results. In addition, parking requirements have tended to follow national standards—only recently have regional differences emerged in the context of livable community initiatives.

The research design is informed by the literature finding that parking requirements are often based on "rules of thumb" rather than actual parking utilization data (Willson 1995). A survey objective, therefore, was to systematically capture these rules of thumb. Survey questions focused on requirements for office, manufacturing, warehouse, and medical buildings.

A telephone survey allowed a large sample size and made it possible to follow up on open-ended questions. Open-ended questions provide planners' thoughts unbiased by suggested response categories. The surveyors contacted all local jurisdictions in southern California in the fall of 1995 and completed surveys for 138 of 150 possible local jurisdictions. The average 1990 population of the cities surveyed is 85,255, so perspectives from a wide range of jurisdiction sizes are included. (The average population is 59,458 if the City of Los Angeles is excluded.) The survey was directed to planning directors and senior planning managers who are familiar with planning and parking issues. The respondents were planning directors/community development directors (20%), senior planners/planning managers (30%), associate/assistant planners (32%), and others (17%).

Analysis of Survey Responses

The interpretation of the survey results used knowledge gained in a series of parking management demonstration projects conducted in a variety of southern California cities from 1996 to 1998. These projects were conducted under the Mobile Source Reduction Program of the South Coast Air Quality Management District. Presentations, interviews, and focus groups with local agencies produced insights into the issues and motivations of those involved in parking policy.

Survey questions asked about frequent workplace parking issues, the rationale for establishing minimum parking requirements, the frequency with which requirements are modified, and sources of information about parking demand. The survey concluded with a series of questions designed to identify attitudes that affect the prospects for reforming minimum parking requirements.

Workplace Parking Issues

Table 1 shows that the most common response to a question about workplace parking issues was that there were *no* important issues. The next most frequent response was parking *undersupply*. Taken together, these responses suggest that calls to reduce excessive minimum parking requirements may not resonate in many local communities.

The concern with workplace parking undersupply is surprising since other research points to oversupplies of parking. In reviewing comments made by respondents, these undersupply issues occurred in older areas, such as downtowns or areas with legal nonconforming uses, areas where shifts in use or intensity of use have occurred, and areas where different uses compete for parking (e.g., beach parking versus retail parking). Most of these concerns per-

Table 1
Workplace Parking Issues[a]

Question: What are the most important workplace parking issues in your community?

	Number of Times Ranked 1st, 2nd, or 3rd		*Number of Times Ranked 1st*	
No parking issues	30	(20%)	30	(26%)
Parking undersupply	27	(18%)	22	(19%)
Determining appropriate number of spaces	16	(10%)	15	(13%)
Overspill into neighborhoods	15	(10%)	10	(9%)
Land-use intensification	11	(7%)	8	(7%)
Other	54	(35%)	27	(23%)
Multiple unranked answers	N/A		4	(3%)

[a] N = 116.

tain to past development patterns and/or parking management, not parking for new projects.

The remaining responses include determining the appropriate number of spaces, overspill issues, and land-use intensification. The "other" category includes a wide variety of responses, such as parking space size, circulation, safety, convenience, cost, access/egress, handicap parking, and parking oversupply. *Only three respondents identified parking oversupply as an issue.*

The apparent satisfaction with workplace parking conditions is further indicated in responses to the question: "Do current minimum parking requirements result in an appropriate level of parking for workplaces?" Using an answer scale of "almost always," "most of the time," "about half the time," "sometimes," and "seldom," 44 percent of respondents said "almost always" and 46 percent said "most of the time." Only 10 percent of the respondents expressed dissatisfaction with their current requirements.

Two issues should be noted in interpreting these results. First, no respondent offered evidence from postoccupancy studies to back up their answer, so these ratings are based on perceptions, not empirical study. In a previous study, the author noted that the impression gained in driving by a site is that parking utilization is greater than that determined in actual utilization counts (Willson

1992b). This occurs because the most visible spaces are generally those that are the most highly utilized. In addition, response questions are based on the respondent's judgment of "appropriate," which may vary from a transit service or regional perspective on that issue.

Rationale for Minimum Parking Requirements

Understanding planners' *reasons* for establishing minimum parking requirements provides a basis for designing effective parking reform programs. Table 2 shows that the most frequent reason for establishing minimum parking requirements for workplaces was to "ensure an adequate number of spaces." This tautological response indicates that many planners do not articulate the public objectives that underlie having "adequate spaces."

Other responses include avoiding parking spillover onto adjacent streets, maintaining traffic circulation, and avoiding parking spillover onto adjacent properties. The response "ensuring the economic success of the project" indicates that some planners replace the developer's judgment of market feasibility with their own, claiming a longer term perspective. The "other" response includes factors such as consistency with regional and national standards, land-use planning issues, safety, convenience, and aesthetics.

Table 2
Rationale for Minimum Parking Requirements[a]

Question: : Why does your jurisdiction establish minimum parking requirements for workplaces?

	Number of Times Ranked 1st, 2nd, or 3rd		*Number of Times Ranked 1st*	
Ensure an adequate number of spaces	65	(38%)	52	(39%)
Avoid spillover parking on local streets	50	(29%)	31	(23%)
Maintain traffic circulation	21	(12%)	9	(7%)
Avoid spillover parking on adjacent properties	14	(8%)	5	(4%)
Ensure economic success of project	4	(2%)	3	(2%)
Other	18	(11%)	16	(12%)
Multiple unranked answers	N/A		18	(13%)

[a] N = 134.

These issues describe a problem-avoiding, impact-mitigating perspective. Planners fear that if a project is undersupplied with parking, there will be public problems (in neighborhoods and increased traffic) or that the city may have to provide additional parking facilities. This concern is valid when on-street parking is not properly regulated and/or priced, although there are many methods for addressing these potential impacts, such as parking permit programs, parking meters, access and/or pricing controls for off-street parking, and enforcement of parking regulations. If not resolved through innovative programs, the impact mitigation perspective will continue to dominate parking policy.

Parking requirements can act as an indirect form of density and growth control. In this study, the researchers hypothesized that this would be a hidden agenda for minimum requirements. Planners were asked: "Do minimum parking requirements have the effect of limiting project density (as opposed to FAR, building coverage, or setback requirements)?" The majority of respondents said yes: 57 percent said "almost always" or "most of the time." Parking requirements, therefore, fulfill dual functions—requiring the provision of parking and limiting density. If parking requirements limit density to less than the permitted FAR, they represent a "hidden" FAR policy.

Modification of Requirements

Slightly more than half of the survey respondents had revised some aspect of their workplace parking requirements in the last five years (52%, n = 133). This is a sizable proportion, but the changes are not usually comprehensive revisions. In a separate question, a smaller, but significant, proportion of respondents (37%) had required, commissioned, or conducted parking demand or utilization studies in the last five years.

To understand whether parking requirements are implemented as mandated in the code, respondents were asked if developers sought four types of parking changes: (1) supplying more than code requirements, (2) reductions based on shared parking, (3) reductions without shared parking, and (4) fulfilling code requirements with off-site covenants. Most respondents said that their jurisdictions deal with all four categories of changes on some occasions. A small group (between 3% and 14%, depending on the type of change) said they never deal with changes. The most frequent modification was using off-site covenants, followed by reductions based on shared parking.

Sources of Information on Parking Demand

Shoup (1995) criticizes planners for unscientific methods of determining parking requirements and their failure to recognize the effect of price on demand. The survey results support his criticisms—they indicate that the common practice is to collect information on neighboring cities' parking requirements. This strategy is inexpensive and avoids veering far from norms. However, this is a faulty strategy if neighboring requirements are out of line with actual parking demand characteristics. Table 3 summarizes the information sources planners use.

Fifty-five percent of the respondents consult more than one type of information, so nearby cities' requirements are not the only influences. Publications by the ITE, American Planning Association (APA), and Urban Land Institute (ULI) are commonly used. Unfortunately, these sources usually provide national averages that may not be applicable to local conditions. Ratios are based on measurements of utilization where parking is usually free and transit

Table 3
Modification of Requirements[a]

Question: What sources of information do you normally use to set minimum requirements for workplaces?

	Number of Times Ranked 1st, 2nd, or 3rd		*Number of Times Ranked 1st*	
Survey nearby cities	82	(36%)	58	(45%)
Institute of Transportation Engineers handbooks	46	(20%)	19	(15%)
American Planning Association/Urban Land Institute publications	26	(12%)	9	(7%)
Commission parking studies	8	(4%)	4	(3%)
Use current standards	7	(3%)	6	(5%)
Traffic engineer	7	(3%)	1	(1%)
Other	44	(19%)	23	(18%)
Don't know	6	(3%)	6	(5%)
Multiple unranked answers	N/A		3	(2%)

[a] N = 129.

service is limited. Without local studies, planners have little information with which to judge whether national averages are appropriate. "Commission parking studies" was an infrequent response, suggesting that local parking demand data are rarely used in setting parking requirements.

The survey also asked planners a series of questions about trends that affect parking demand. The top responses were ridesharing (20%) and transit development (20%), suggesting some awareness of the relationship to transit and other nonsingle-occupancy vehicle modes. Although planners recognized that parking requirements might change as a result of increases in nonautomobile commuting, there was little recognition of the other direction of causality; namely, using parking policy to support increases in transit use. Local planners prefer to wait for more extensive transit service, rather than change their policies in ways that would support the development of transit markets, and therefore lead to more service.

Attitudes

Planners' attitudes help explain their involvement in defining issues, initiating policy studies, and implementing local parking regulations. This does not discount the role that the city council, developers, community groups, and other stakeholders have on policy, but planners shape how issues are studied, presented, and adopted as policy (Dalton and Burby 1994). The survey included six statements to which respondents indicated "strong agreement," "agreement," "neutrality," "disagreement," or "strong disagreement." Table 4 summarizes the number of responses agreeing or disagreeing with the statements.

There is agreement that parking charges reduce parking demand. This is a significant shift from 10 or 20 years ago when the view was that commuters would drive no matter what the cost of parking. However, many planners also see free parking as a right of employment. Planners with this perspective are not likely to support parking pricing or reductions of minimum parking requirements even if they acknowledge the potential effectiveness of these policies in reducing demand.

There was significant agreement that developers should be allowed to use

Table 4
Survey Responses to Attitudinal Questions[a]

	Agree or Strongly Agree		*Disagree or Strongly Disagree*	
A. Parking charges reduce the level of solo driving and parking at a workplace	93	(69%)	30	(22%)
B. Developers should be allowed to fulfill some of their parking requirement by using underutilized parking in developments that are close by	84	(62%)	32	(24%)
C. Free parking at workplaces is a right of employment	72	(53%)	34	(25%)
D. On-street parking should be priced to manage its use	64	(47%)	42	(31%)
E. Current parking policies require developers to oversupply parking	49	(36%)	63	(47%)
F. Developers should determine the amount of parking to be provided in projects	14	(10%)	114	(84%)

[a] N = 135. Note: Row totals do not sum to 135 and percents do not total to 100 because they exclude responses of "neutral" or "don't know."

adjacent underutilized parking; many cities already permit this. This is a shift from the view that parking should be considered on a site-by-site basis. There was partial agreement that on-street parking should be priced. This is significant because on-street pricing is an effective tool for avoiding spillover parking from off-street facilities.

Planners disagreed with the statement that current policies require an oversupply of parking. Future studies could focus more specifically on what types of workplaces lack parking because other research shows that office buildings are generally oversupplied with parking.

Planners strongly disagreed with the statement that developers should be allowed to determine the supply of parking. Survey respondents do not trust developers to provide the correct amount of parking even though developers bear the economic consequences of creating a building that does not meet market demands for parking.

Prospects for Change

The survey findings present a challenge for policy-makers and transit agencies wishing to encourage local governments to reform their parking requirements. Many local planners are satisfied with current requirements. Some disagree with the premise of recent policy initiatives. Their perspectives might change, however, if they learn more about the unintended consequences of excessive parking requirements and the availability of management tools to deal with specific parking problems.

The local planner's perspective could be looked at in terms of a balancing act between requiring too little parking and requiring too much parking. Figure 1 provides a diagram of this balancing act. The risks of requiring too little parking are perceived more strongly than the risks of providing too much parking. Furthermore, the availability and effectiveness of parking management techniques for addressing undersupplied parking are not well understood. Finally, the risks of requiring too much parking are not prominent in local government priorities.

The challenge in moving parking policy forward is reconciling the differences in priorities among the parties concerned with parking. Policy-makers at the regional, state, and federal levels think about parking policy in the context of transportation, environmental quality, and urban form. Their reform initiatives come from that tripartite view and support transit agencies' concerns with efficiencies in service provision, fiscal health, and an expanded ridership base. Local jurisdictions, on the other hand, think about impact mitigation, traffic circulation, neighborhood disruption, and economic development (see Kendig 1987; Reed 1984).

Status quo parking policies *do* address many local planners' concerns, albeit in a way that exacerbates problems at the regional scale. For example, if a city lowers development density through excessive parking requirements, it reduces total development and trips generated per square mile in that city. Paradoxically, however, it may increase regional vehicle miles traveled (VMT) because lower-density regions generally have greater automobile dependence. Transit service becomes more difficult to provide. The city that limits density may also experience an increase in through traffic. This logic, however, is gen-

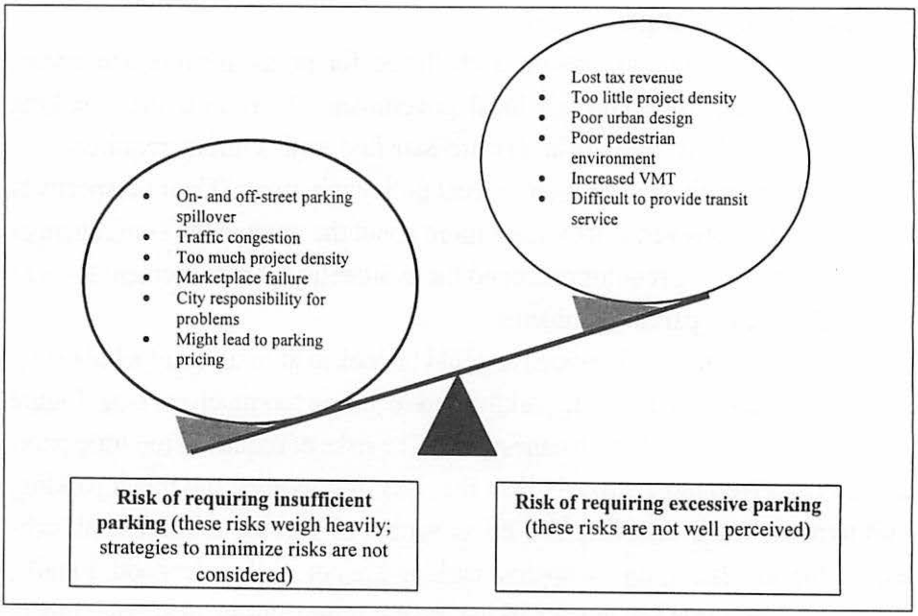

Figure 1. Status quo in the parking requirement balancing act

erally not persuasive to local decision-makers. Therefore, local perspectives on parking requirements must be addressed, and local problems must be solved before progress will be made on local reform. The sections that follow discuss three issues that must be addressed: risk, revenue and fiscal solvency, and education. The article concludes by presenting strategies for supporting parking requirement reform efforts.

Risk

Current parking requirements reduce the risk of undersupplying parking, which avoids creating a municipal responsibility for solving a potential parking problem. This risk can be minimized by adopting strategies for responding to more intense future uses of a development. Such uses might lead to spillover parking, for example, but residential permit parking and off-street parking controls can address that issue. Innovative development agreements can include performance requirements for future property owners/tenants and require remedies if parking spillover occurs. Finally, parking pricing and cash-out can alter parking demand and shared-parking strategies can balance differences in parking demand among individual developments.

Municipal Concerns about Revenue and Fiscal Solvency

It is an understatement to say that any policy that affects tax revenues receives great scrutiny. Parking policies that are different than the "norm" raise concerns about competitive positions with neighboring cities. Regional or subregional cooperation on this issue can reduce this risk. Planners also want parking regulations that are inexpensive and simple to administer. They may be reluctant to adopt more complex agreement provisions that run with the land. Paradoxically, even though planners are very concerned with revenues, they do not appear to have linked that concern with the effect that excessive parking requirements have in lowering density, and therefore lowering tax revenues.

Need for Education

There is a strong need to educate planners, planning commissions, neighborhoods, business groups, developers, and lenders about parking policies. Rules of thumb have become ingrained. Education efforts should challenge the notion that extensive transit service is a precondition for changes in local parking requirements. Research shows, for example, that pricing strategies to reduce parking demand are successful even if extensive transit service is not available (Willson 1997). These reductions in parking demand are needed to create a ridership base that will support more extensive transit service.

Strategies for Reform

Planners need information on easily adopted and modified sets of parking reform policies. "Toolbox"-type documents, workshops, and incentive grants can garner local support for parking studies. Bringing stakeholders together is a time-consuming but necessary process of considering new parking policies. Regional agency and transit agency funding of local parking utilization studies and policy development can move parking issues up on local governments' priority lists (Michael R. Kodama Planning Consultant et al. 1996).

There are differences among city characteristics and planners' attitudes that affect the type of strategy used to modify parking requirements for a specific city. Population density and attitudes about parking charges provide a useful way of organizing the different circumstances. Table 5 groups the sample cities in a two-by-two matrix, with each quadrant showing the number of cities from the study sample. The quadrants labeled "high density" are cities with a population density greater than the 66th percentile (6,812 persons per square mile). The quadrants labeled "conservative" are cities whose planners indicated "strongly agree" or "agree" with the statement that free parking is a right of employment.

The text in each quadrant suggests high-potential strategies and key arguments for initiating parking requirement reform in each context, assuming that a public agency (usually the city) is taking the lead. The strategies used in any particular city must be carefully tailored to local conditions, of course, so local studies and policy processes should be carried out. All scenarios should include education activities that increase stakeholder awareness of the opportunity cost of status quo parking policies.

The population density distinction relates to the cost of land and parking facilities. The higher density the city, the more likely that pricing can be used as a management tool and that cost-driven private interests in reforming parking requirements will emerge. The conservative/progressive distinction has a bearing on the degree to which arguments for parking reform can be based on linkages to broad community development strategies. For cities that have a conservative approach to parking, the strongest arguments relate to efficiency of land utilization and avoiding the wastefulness of excessive parking. For cities that have progressive views on parking, the same arguments have merit, but additional arguments about reducing automobile dependence and achieving sustainable land use and community development may be effective.

The reform of minimum parking requirements is needed, indeed overdue, if the land-use and transportation goals of regional agencies and transit providers are to be achieved. Transit providers face a great challenge if they must compete with free parking and provide service in low-density areas dominated by surface parking lots. Regardless of the logic of the case for changes in parking requirements, however, proposals must address the issues that matter most to local governments, such as traffic mitigation, spillover parking, and risk avoidance.

The development community may lead efforts to reform parking requirements in high-density, high-cost areas, but local governments in all types of

Table 5
Suggested Parking Policy Approaches, by City Characteristics

Attitude toward Parking Pricing

City Density	← *Progressive*	*Conservative* →
Low ↑	**Quadrant 1: Low Density, Progressive** **(n = 44)** ***Transitioning to a priced environment*** *Strategies* • Revise local ordinances to require a parking level equal to average demand; use shared parking to address land uses with high parking demand. • Price on-street parking. • Create urban design guidelines that facilitate shared parking. • Develop land-use and transportation plans for the transition to higher density community and a priced parking environment. *Key arguments: link parking policy to environmental and community development goals.*	**Quadrant 2: LowDensity, Conservative** **n = 49** ***Land-use efficiency and parking management*** *Strategies* • Revise local ordinances to require a parking level equal to peak demand for specific land uses. • Implement on-street parking restrictions to limit spillover parking (time limits and meters). • Monitor parking utilization in key districts. • Develop site-specific shared-parking programs. *Key arguments: identify tax revenue forgone when excessive parking requirements lower density of development; emphasize efficiency issues.*
High ↓	**Quadrant 4: High Density, Progressive** **n = 22** ***Markets and agreements replace regulation*** *Strategies* • Lower or eliminate minimum parking requirements; use development agreements with performance clauses to address parking issues. • Facilitate shared-parking arrangements between property owners. • Price on-street parking. • Engage private sector interest and initiative in supplying and managing parking. • Form parking districts to use and manage shared pools of parking. *Key arguments: as above, plus emphasize the links between parking policy and transit use, lowering of development costs, environmental and community development goals. Make part of Smart Growth/livable community agenda.*	**Quadrant 3: High Density, Conservative** **n = 23** ***Sophisticated development regulation and parking management*** *Strategies* • Revise local ordinances to require a parking level equal to peak demand for specific land uses. • Price on-street parking. • Develop site-specific and districtwide shared-parking arrangements. • Create development agreement provisions that require property owners to remedy parking deficiencies. *Key arguments: as above, plus emphasize the economic advantages of devoting capital to buildings rather than parking structures, ability to create economically feasible brownfield development projects.*

circumstances will need encouragement and support if they are to develop the next generation of local parking requirements and policies. Transit agencies can play an important role in supporting that activity. They may support the efforts of transportation management organizations, regional entities, or cities, or they may undertake such initiatives on their own. Although many transit planners have been concerned about these issues for decades, taking a more proactive role in parking policy requires a paradigm shift among managers and their boards. This broadening of perspective, from concern with service and operations to concern with the land-use and transportation conditions that affect the market for transit, can yield great benefits for transit.

Linking parking requirements to transit policy is an effective way of harnessing some of the current interest in Smart Growth/livable community concepts. With broad support, hopefully the next generation of parking requirements will be set in a broader framework that reflects land-use, community development, environmental, and transportation goals. Transit-friendly parking requirements are long overdue.

References

Baldassare, M., J. Hassol, W. Hoffman, and A. Kanarek. 1995. Possible roles for regional government: A survey of city planning directors in California. *Journal of the American Planning Association* 62: 17–29.

Berke, P., and S. French. 1994. The influence on state mandates on local plan quality. *Journal of Planning Education and Research* 13: 237–250.

Committee for Study on Urban Transportation Congestion Pricing. 1994. *TRB special report 242: Curbing gridlock, Volume 1.* Washington DC: National Research Council.

Dalton, L., and R. Burby. 1994. Mandates, plans, and planners: Building local commitment to development management. *Journal of the American Planning Association* 60: 444–462.

Gillen, D. 1977. Estimation and specification of the effects of parking costs on urban transportation mode choice. *Journal of Urban Economics* 4: 186–189.

Kendig, L. 1987. *New standards for nonresidential uses.* APA Planning Advisory Service Report #405. Chicago: American Planning Association.

Michael R. Kodama Planning Consultant, Richard Willson, and William Francis and Associates. 1996. *Using demand-based parking strategies to meet community goals.* Los Angeles: The Mobile Source Reduction Committee.

Mildner, G., J. Strathman, and M. Bianco. 1997. Parking policies and commuting behavior. *Transportation Quarterly* 51 (1): 111–125.

Reed, C. 1984. *The Zoning Report* 2, 1–8.

Regional Transportation Authority. 1998. *Opportunity costs of municipal parking requirements.* Chicago: Regional Transportation Authority.

Shaw, J. 1997. Parking legislation and transportation plans. *Transportation Quarterly* 51 (2): 105–115.

Shoup, D. 1995. An opportunity to reduce minimum parking requirements. *Journal of the American Planning Association* 61: 14–28.

Strathman, J., and K. Dueker. 1996. Transit service, parking charges, and mode choice for the journey to work: An analysis of the 1990 NPTS. *Journal of Public Transportation* 1: 13–38.

Willson, R. 1992a. Estimating the travel and parking demand effects of employer-paid parking. *Regional Science and Urban Economics* 22: 133–145.

Willson, R. 1992b. Suburban parking economics and policy: *Case studies of office worksites in southern California.* Report FTA-CA-11-0036-92-1. Washington, DC: U.S. Department of Transportation.

Willson, R. 1995. Suburban parking requirements: A tacit policy for automobile use and sprawl. *Journal of the American Planning Association* 61: 29–42.

Willson, R. 1997. Parking pricing without tears: Trip reduction programs. *Transportation Quarterly* 51: 79–90.

Willson, R., and D. Shoup. 1990. Parking subsidies and travel choices: Assessing the evidence. *Transportation* 17: 141–157.

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