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SENSITIVITY ANALYSIS OF COMMUNITY SAVINGS DUE TO CHANGE-OF-MODE OPERATIONS

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This study is concerned with a sensitivity analysis of the community savings provided by successful change-of-mode (park-and-ride) facilities in medium to large U.S. cities. The research was an early attempt to generalize the locational aspects of change-of-mode facilities and their benefits to the community. The determination of the community savings due to the diversion of trips from highway to change-of-mode facilities is a prerequisite in assessing the feasibility (success of park-and-ride facilities). Community savings (the summation of both user and nonuser benefits) are computed as the difference in travel costs by highway alone and or by change-of-mode facilities. Travel costs are simulated in a deterministic fashion and by using average unit costs for cities of different sizes and for different locations within a given city. The simulated community savings data are then used to develop a linear multiple regression equation to predict the savings.

•A BALANCED transportation system uses each different transportation mode where it is most efficient and provides for a smooth interface connection among the different modes. Efficiency and coordination are some of the prerequisites for good transportation planning. Change-of-mode parking facilities, also known as park-and-ride lots, perform the role of a connecting link between passenger car and public transit. The passenger car is best used in the collection of the trips in areas of low-density trip ends. At the same time, change-of-mode parking increases the demand for public transit along established travel corridors by extending the service area of transit stations. Change-of-mode parking reduces the demand for parking in downtown (CBD) areas by diverting such demand to locations of lower land use density and lower land value. Downtown space is too valuable for the long-term storage of the work-trip vehicle. Finally, the public concern for energy conservation should provide a higher acceptance of change-of-mode operations than of full transit service.

The objective of the study is to determine the economic feasibility of change-of-mode parking facilities. Only the benefits (community savings) are reported on. For this purpose, a linear multiple regression is developed to estimate the community savings due to change-of-mode in different size U.S. cities and for different locations within a given city.

Savings are defined as both user and nonuser benefits although most of the community savings are due to savings accruing to change-of-mode users. Differential land productivities and pollutant emissions savings are the only real nonuser economic factors. Social savings and savings to highway users from the diversion of some of the users to change-of-mode are not computed or used, since it is felt that such savings are small because of the relative insignificance of change-of-mode effects on existing travel patterns. For simplification, only first-order benefits and costs are quantified. For example, the study ignored the increased efficiency of the workers due to the ease of travel by transit for the congested portion of the work trip.

TRAVEL COSTS

The travel costs based on the passenger car are vehicle operation, accidents, and pollution. The transit fare is the only cost used for travel by transit. Emphasis was placed on easily quantified, first-order factors. The researchers ignored the subsidies received by both transit and the private automobile industry. An example of the latter would be the extensive oil depletion allowance that is reflected in lower fuel costs. The units for travel costs by passenger car are in dollars per vehicle mile (kilometer). The units for travel costs by transit are in dollars per passenger-mile (kilometer). There are also other cost elements that enter in the analysis of commuter savings, and these will be discussed later.

Although a generalized model is the objective, some categorization is used to reduce the variance of the developed model. Driving conditions change with the type of highway being used; therefore, unit travel costs are developed by highway type. For this same purpose, the street network is subdivided into four types: expressways, arterials, local streets, and downtown streets. Table 1 gives the unit costs used (in 1970 dollars) for travel by passenger car (1, 2, 3, 4, 5, 6, 7).

Vehicle operating costs that are computed as time costs include licenses, depreciation, vestcharge (1, p. 71), insurance, parking, tolls, and taxes. Oil, gasoline, maintenance, and tires were expressed as mileage items (Table 2). Differences in travel speed and the frequency of stops are the two elements of driving conditions that affect the vehicle operating costs.

Pollution costs are computed on the basis of cost estimates for proposed exhaust control devices (Table 3, Figure 1). It is expected that damage costs from automobile emissions are larger than the control costs used here. The difficulty of establishing the true costs of pollution, such as health, cleaning bills, and house painting, necessitates extensive data collection. Unit accident costs used include all types of accidents (fatal, injury, property damage) and are computed for passenger cars in urban areas (Table 3). Unit accident costs are based on $4,670/average accident.

Transit fare costs are based on existing fares in Cleveland (rail) and Milwaukee (bus) and on the proposed fares for San Francisco (rail) (8, 9, 10). Equation 1 is developed to estimate transit fares in dollars per passenger-mile (kilometer) (Figure 2).

$$\text{Transit fare} = 0.20\ (\text{transit trip length})^{-0.646} \qquad (1)$$

Equation 1 is expressed in terms of 1970 dollars, and the transit trip length is in miles (kilometers).

RELATED COSTS

The related costs are those that account for travel time, land productivity, and parking fees. Since change-of-mode trips are work trips, one should account for the cost of time. When a parcel of land is used as a parking lot or for a parking garage, a land productivity loss occurs since the land could have been used for more productive purposes. The vehicle storage area is transferred out to lower valued land on the periphery.

The value of time for work trips is assumed to be equal to $1.25/person hour (11). Based on inflation occurring since 1970, any selected value of time would be suspect. Assuming average travel speeds and average car occupancy, the travel time cost in dollars per vehicle mile (kilometer) becomes equal to 0.187 for CBD streets, 0.100 for local streets, 0.081 for arterials, and 0.046 for expressways (3, 12, 13) (Table 3).

Similarly, the cost of time for travel by transit in dollars per passenger-mile (kilometer) is equal to 0.059 for express bus and 0.042 for rapid transit (3, 8, 9, 13) (Table 4). Time is also spent at both ends of a trip. This terminal time is assumed to be equal to

Table 1. Unit travel costs for passenger cars.

Highway Type	Vehicle Operation[a]	Pollution[a]	Accidents[a]
CBD streets	0.143	0.023	0.007
Local streets	0.128	0.015	0.007
Arterials	0.123	0.012	0.005
Expressways	0.113	0.006	0.002

Note: 1 mile = 1.6 km.

[a]All values are in dollars/vehicle mile (kilometer).

Table 2. Cost items for vehicular operation.

Item	Cost ($/vehicle mile)	Item	Cost ($/vehicle mile)
Time		Mileage	
Licenses, depreciation, and vestcharge	0.0339	Engine oil	0.0016
Insurance	0.0172	Gasoline	0.0253
Garage, parking, and tolls	0.0180	Maintenance	0.0155
Property taxes	0.0033	Tires	0.0041
Total	0.0724	Total	0.0465

Note: 1 mile = 1.6 km.

Figure 1. Control cost of probable reduction in emission of pollutants.

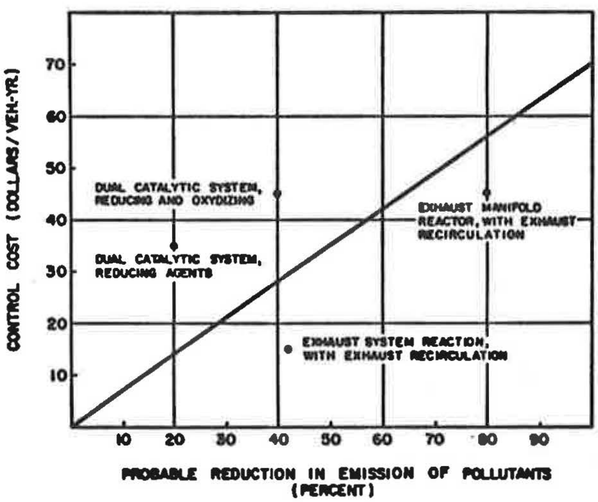


Table 3. Pollutant emissions, accident rates, and travel speeds, by highway type.

Highway Type	Emissions (lb/vehicle mile)	Accident Rate (per 10^8 vehicle miles)	Travel Speed (mph)
CBD streets	0.545	493	8
Local streets	0.355	513	15
Arterials	0.292	340	19
Expressways	0.152	160	32

Note: 1 lb = 0.45 kg. 1 mile = 1.6 km.

Figure 2. Transit fare to and from CBD.

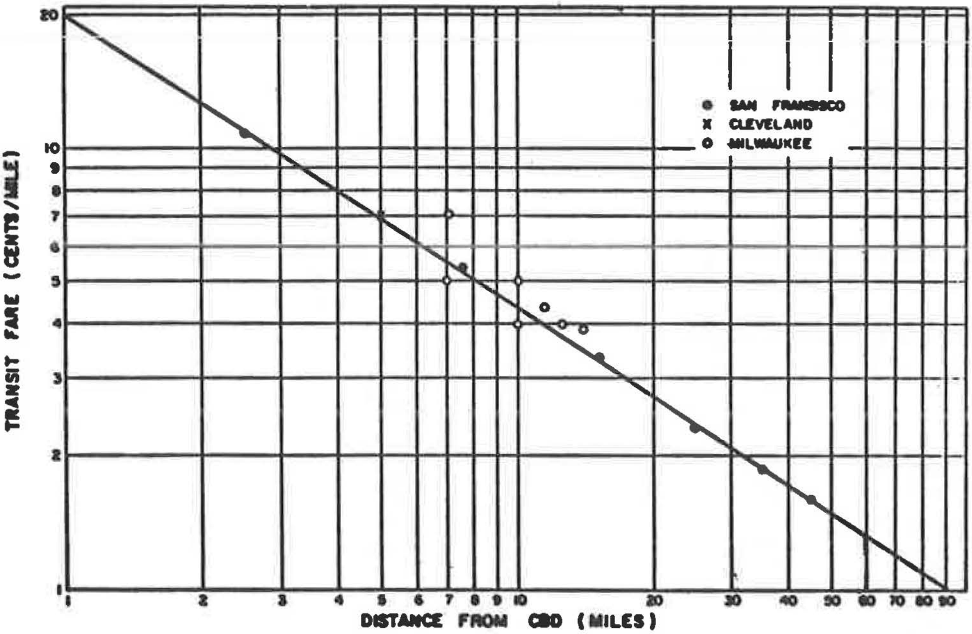
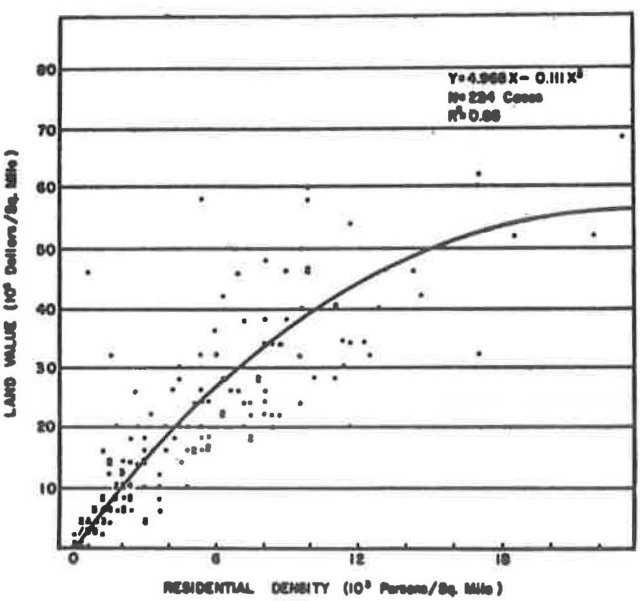


Table 4. Public transit travel speeds and terminal time costs.

Item	Average Travel Speed (mph)	One-Way Terminal Time ($/commuter)
New rapid rail	38	
Kiss-and-ride		0.135
Park-and-ride		0.156
Express bus	21	
Kiss-and-ride		0.208
Park-and-ride		0.229

Note: 1 mile = 1.6 km.

Figure 3. Land value versus residential density.



7 min/person for a one-way trip by passenger car (14), 6.5 and 10.0 min/person for a one-way kiss-and-ride trip by rail and bus respectively, and 7.5 and 11.0 min/person for a one-way park-and-ride trip by rail and bus respectively (Table 4).

The loss of land productivity is assumed to be equal to 10 percent of the land value. In 1970, it was still reasonable to expect rental properties in the CBD to provide an annual net return of 10 percent of the property value. Figures 3, 4, and 5 are used to determine the land value for a change-of-mode lot in different size cities. The land value of downtown parking is assumed to be equal to $2,000/stall, based on some economical number of garage floors (15).

Parking fees in the CBD are computed on the basis of existing rates and adjusted to 1970 dollars (15). Equation 2 is developed to estimate parking fees in the downtown of metropolitan areas in dollars per vehicle (Figure 6). This estimate only applies to work trips.

$$\text{Downtown parking fee} = 0.84 \log \frac{(\text{metropolitan area population})}{34} \quad (2)$$

The metropolitan area population is in thousands of persons.

All of the related costs are expressed in terms of 1970 dollars. It is important to note that highway and transit construction and operation costs are not to be included in the analysis of commuter and community savings from change-of-mode facilities. The purpose of the analysis is to assess the feasibility of change-of-mode facilities and not to compare public transit and highway.

COMMUNITY SAVINGS

Community savings (both user and nonuser) are defined as the difference in total costs between driving all the way to the CBD and driving to a change-of-mode parking lot and taking transit for the remaining part of the trip. A trip is defined as a two-way trip, from home to work and work to home.

Simulation Program

A computer program was written in FORTRAN IV to deterministically simulate the community savings based on the average trends already reported.[1] A total of 1,008 different conditions are generated in a factorial design for which community savings are computed. The savings are analyzed for a factorial combination of six populations of metropolitan areas (0.5 to 7 million persons), seven distances of the parking lot to the CBD [1 to 20 miles (1.6 to 32 km)], two types of transit (bus and rail), four ratios of kiss-and-ride stalls to total stalls (1 to 15 percent), and three distances of the parking lot to the street access (2 to 8 blocks).

The simulation program computes the cost of traveling by passenger car to the CBD and the cost of traveling by passenger car to a change-of-mode lot and taking public transit to the CBD. The two travel alternatives are shown in Figure 7. The elements of cost for a trip by passenger car to the CBD are

1. Vehicle operation,
2. Vehicle emissions,
3. Vehicle accidents,

[1] A copy of the program is in an appendix that is available in Xerox form at cost of reproduction and handling from the Transportation Research Board. When ordering, refer to XS-62, TRR 557.

Figure 4. Variation of land value with distance from highway.

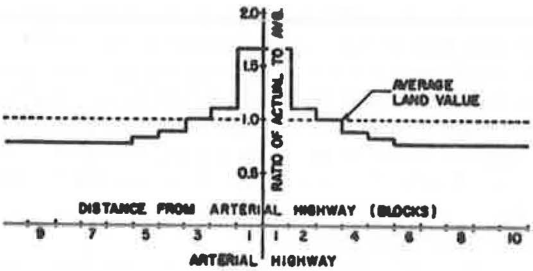


Figure 5. Residential density as function of location within city and metropolitan area size.

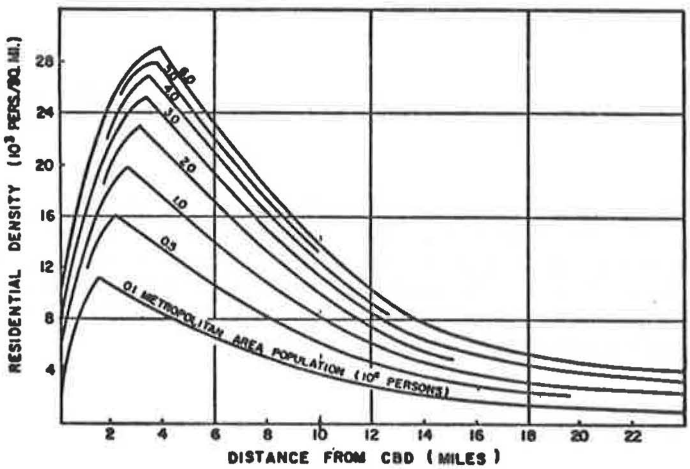


Figure 6. Variation of CBD parking fee with metropolitan area size.

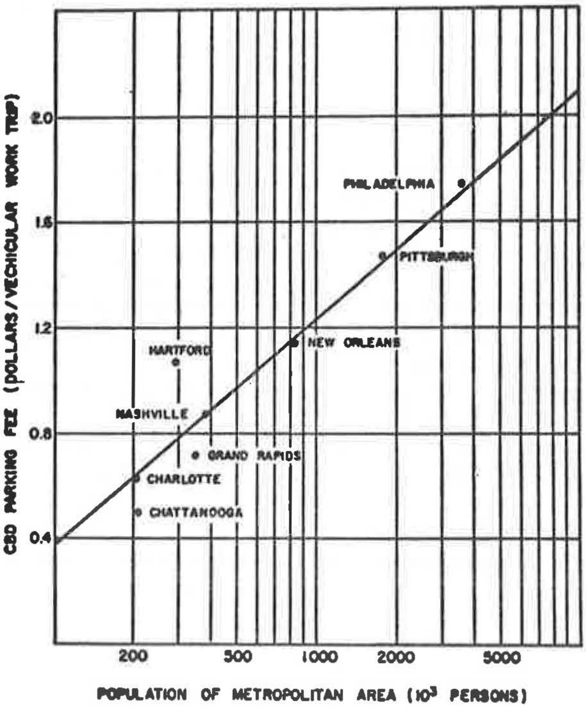


Figure 7. Change-of-mode process.

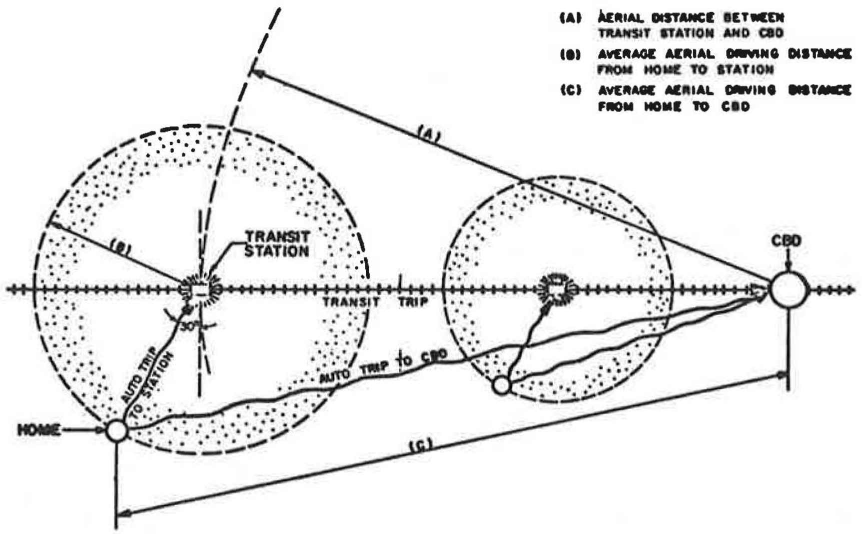
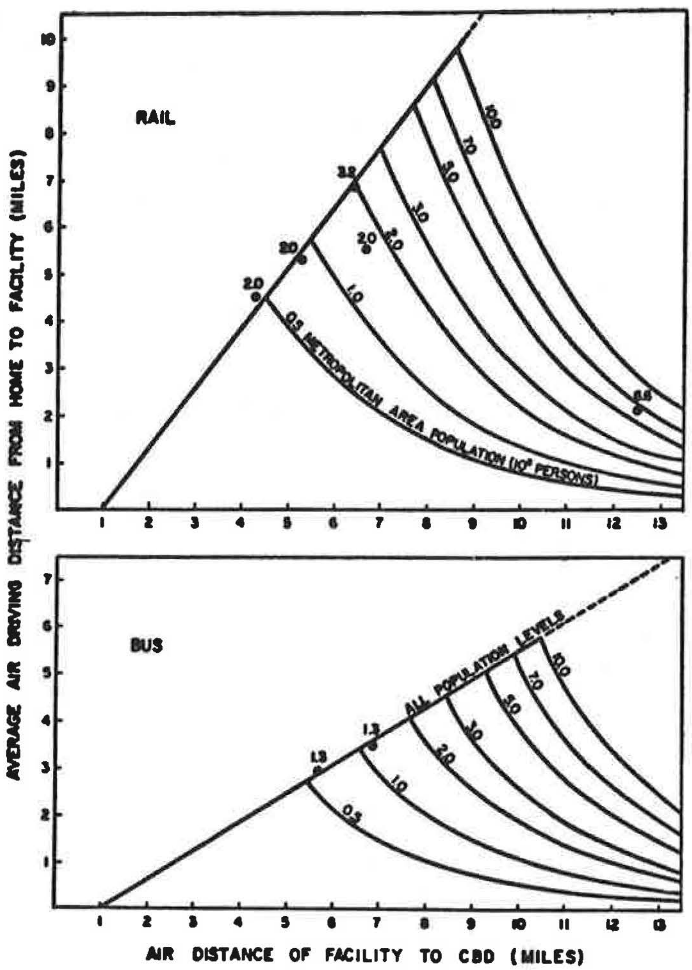


Figure 8. Average driving distance from home to change-of-mode parking lot.



4. Travel time,
5. Terminal time,
6. CBD parking fee, and
7. Loss of land productivity in downtown.

The elements of cost for a change-of-mode trip to the CBD are

1. Vehicle operation for automobile portion of the trip,
2. Vehicle emissions for automobile portion of the trip,
3. Vehicle accidents for automobile portion of the trip,
4. Travel time for automobile portion of the trip,
5. Total terminal time,
6. Travel time for transit portion of the trip,
7. Transit fare, and
8. Loss of land productivity due to change-of-mode lot.

A number of cost elements have been developed based on vehicle miles (kilometers) or passenger-miles (kilometers). Since actual costs are to be determined for a trip, the need for estimating trip lengths is apparent. Figure 8 shows the average airline distance from a commuter's home to a change-of-mode lot as a function of the airline distance of the change-of-mode lot to the CBD and the size of the metropolitan area. This figure was developed from the results of surveys conducted in Cleveland, Milwaukee, Boston, and Chicago (8, 9, 16, 17, 18). Airline distances were transformed to over-the-road distances for the purposes of simulation. As shown in Figure 8, the average driving distance from home to change-of-mode lot decreases beyond a given distance of change-of-mode lot to the CBD. This is due to the start of finger type of land use development along radial corridors and not to the unwillingness of commuters to drive additional distances.

Travel distances that are less than 0.4 miles (0.6 km) are made on local and downtown streets. Travel distances in excess of 1.9 miles (3 km) are made on expressways. The balance between 0.4 and 1.9 miles (0.6 and 3 km) is the distance driven on arterials (19).

The community savings are computed in dollars per park-and-ride vehicle per day. In order to accomplish this, cost units are transformed from dollars per vehicle mile (kilometer) and dollars per passenger-mile (kilometer). The key for the transformation of unit costs is the number of change-of-mode passengers (park-and-ride and kiss-and-ride) per park-and-ride vehicle. The data collected for the general purposes of the research project and used for estimating the demand at change-of-mode parking lots (20) were the basis for developing a multiple regression equation to estimate the number of park-and-ride vehicles that use a facility during a 24-hour period, D.

$$\sqrt{D} = -0.705 + 0.009\,Z + 1.964\,B + 1.211\,R + 001\,T^2 + 0.009\,M^2 + 0.049\,F \cdot P - 0.019\,T \cdot R \quad (3)$$

where

D = number of park-and-ride vehicles that use a facility during a 24-hour period,
Z = number of stalls within a change-of-mode parking facility,
B = type of transit transferred to at the facility (bus on highway right-of-way = 0, and rail and bus on exclusive right-of-way = 1),
R = reliability rating of the change-of-mode parking facility,
T = transit service rating at the change-of-mode parking facility,
M = metropolitan area rating for the change-of-mode parking facility,
F = flexibility rating of the change-of-mode facility, and
P = parking fee rating of the change-of-mode facility.

The R^2 for equation 3 is 0.78. Measures of the variables that make up the ratings are detailed elsewhere (20).

A survey conducted recently by the Institute of Traffic Engineers indicated that only one-fourth to one-fifth of the demand at change-of-mode lots is actually diverted from the street network (21). The remaining portion of the demand either did not make the trip before or, as in most cases, already had changed modes but parked on streets in the vicinity of public transit stations.

Results

The simulation program generated savings data for more than a thousand different conditions of metropolitan area size, change-of-mode distance to the CBD, percentage ratio of kiss-and-ride stalls to total stalls, type of transit, and parking lot distance to the street access. These data were fed as input to a packaged step-wise linear multiple regression program; community savings (in dollars per parked vehicle per day) were the dependent variable, and the factors defining a condition were the independent variables. The results of the regression analysis are given in equation 4.

$$\text{Community savings} = 0.40627 + 0.00002p + 0.04498d - 0.15028t - 0.00261k + 0.00193d^2 - 0.000001p \cdot d \quad (4)$$

where

p = size of metropolitan area in thousands of persons,
d = distance of change-of-mode lot to CBD in miles (kilometers),
t = type of transit (rail = 1, bus = 2), and
k = percentage ratio of kiss-and-ride stalls to total stalls.

The R^2 in equation 4 is 0.97, and all of its independent terms are significant at a rate higher than 9,995 in 10,000. Only the parking lot distance to the street access was found to be insignificant in affecting the community savings.

CONCLUSIONS

Under present conditions, the community savings vary from \$0 to \$2 per park-and-ride vehicle per day. Community savings increase in larger metropolitan areas for change-of-mode lots located further from the CBD and for rail transit. Community savings decrease for a higher percentage of kiss-and-ride stalls, and this is due to lower car passenger occupancy for the demand at change-of-mode lots.

The savings that accrue to a community from the use of change-of-mode parking are most sensitive to the location of the parking facility. The further from the downtown the change-of-mode takes place, the larger the unit savings are. However, under this condition, the transit service tends to decline in quality and quantity because of the diseconomy of providing the same service as that found closer to the downtown. In addition, facilities located far from the downtown are under suburban jurisdictions that do not possess and cannot raise the funds required for providing good-quality parking facilities. The park-and-ride demand is thus reduced. The combination of facts thus suggests that the total community benefits would peak at a specific distance from the downtown and would decline from there on. This observation was further substantiated by the literature (25).

ACKNOWLEDGMENT

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INFLUENCE OF PARK-AND-RIDE FACTORS IN MODAL SHIFT PLANNING

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The purpose of this paper is to investigate the use of park-and-ride facilities and municipal parking policies as a means of controlling the modal split in urban areas. A discriminant model was used to examine the reasons why park-and-ride patrons shifted to that mode from a former automobile mode. An attitudinal survey was also used to substantiate the model results. The reduction in travel cost appears to be the main reason for the modal shift. The primary conclusion is that a park-and-ride facility can be used as a planning tool to adjust the modal split if the service is properly designed.

•THE purpose of this paper is to investigate the use of a park-and-ride system to change the modal split in the context of a low-cost option planning framework. This framework has two requirements:

1. A clear understanding of what characteristics a public transportation system needs to attract automobile commuters, and
2. A policy mechanism to implement publicly desirable modal shifts.

A central concept in this approach is to relate demand for new modes, or combinations of existing modes, to satisfactions gained from the attributes of the system rather than to the mode actually used or contemplated. The premise is that a traveler uses a particular mode because it provides him or her with the least undesirable combination of such attributes as travel time, travel cost, walking and waiting time, or travel comfort. If the demand for each combination of attributes can be measured, the effects of new untried systems can be tested, and modal shift predicted.

Mathematical models can be a useful means of exploring and predicting probable effects of various policy options on the modal shift. A few recently formulated disaggregated and stochastic travel demand models based on extant behavior appear to be good for simulating the modal choice of commuters. However, models based on extant behavior are somewhat restrictive because of the unavailability of behavioral data for high levels of service for transit systems. This has led to the consideration of subjective preferences as a data base for model calibration. Clearly, the effect of system changes on modal choice depends on the subjectively perceived relative service levels of the modes available. Therefore, subjective preferences, if reliably measured, can be used to understand new dimensions of transportation demand. This is the approach taken in this study.

A policy mechanism to implement mode shifts requires a philosophical change in the concept of transportation planning as practiced in the past, a change from the traditional concept of planning to meet demand for automobile travel to one of planning to adjust demand based on community objectives. One policy mechanism that can be related to the low-cost option planning framework is disjointed incrementalism, a strategy directed to the identification and solution of problems by incremental changes from the status quo. Braybrooke and Lindblom (1) described disjointed incrementalism as a realistic mechanism for solving problems through the public decision-making process. They imply that this approach is really just a formalization of the usual process of making decisions on public projects. There is no goal achievement orientation in the philosophy as documented, but Steger and Lakshmanan (2) have combined disjointed incrementalism with a forward-seeking goal-oriented process, and these two ideas together form a systematic basis on which future transportation plans can be formulated. This process would (a) model the transportation system, (b) identify transportation problems, (c) establish problem-solving short-term transportation system objectives, and (d) generate alternative strategies to guide transportation policies toward community goals. This combination of incremental problem solving within a long range goal-oriented planning context is an appealing philosophical framework for modal split planning.

Available evidence of sensitivity to parking charges or a parking tax suggests that a policy mechanism based on parking controls conforms to this philosophical planning framework and would be successful in altering modal split on both conceptual and practical grounds. Such a mechanism should include nonprice factors because of the overall sensitivity to time and comfort aspects of system users. These include walking time at the destination and parking time as well as parking fees or a parking tax. For a park-and-ride system, walk times, overall travel times, frequency of buses leaving the park-and-ride terminal, bus fares, transfers, and waiting characteristics of the system are also factors to consider.

This planning procedure is a blend of classical demand modeling and the demonstration project, in which operational improvements are modeled and subsequent effects on the system are monitored. In this case, park-and-ride is defined as a low-cost option. If results are not in the direction desired to reach community goals on modal split, changes in the parking price, supply, or location are designed to correct the previous misallocation.

The idea of formally planned park-and-ride facilities in urban areas appears to have advantages in attracting automobile commuters because such a system provides geographic flexibility as an extension to a conventional bus, rail, or suburban mode and may create efficiencies in line-haul and downtown distribution.

INVESTIGATIVE MODEL

The potential effect of park-and-ride facilities on automobile commuting was investigated by a discriminant, policy-sensitive model applied to data collected in Vancouver, Canada.

The criteria used to define the structure of the model to study the effects of park-and-ride policies were as follows:

1. The model should be responsive to the characteristics of the transportation system, i.e., an abstract modal model;
2. The model should be structured around instrumental variables that could be represented by a realistic municipal parking policy;
3. The model should be disaggregated to account for the differential effects on different social groupings; and
4. The model should be theoretically sound and replicate a logical construct of consumer preferences.

The study used stated preferences to model the propensity of an individual to shift to a park-and-ride system. The model is called a propensity model because prediction of behavior from stated preferences for modal attributes is only possible if those who say they will shift actually do so if the perceived travel system is changed.

The model (4) postulates an indifference surface defining the combination of transportation system attributes (e.g., time, cost, and comfort) preferred by each automobile commuter. If a new set of transportation system attributes are introduced as an alternative to the automobile (in this case by a park-and-ride facility) for each commuter, the closeness of this new set of attributes to his or her travel indifference surface can be examined. The degree of closeness of the new system attributes to any individual's indifference surface defines his or her propensity to shift to the new mode. If the combination of attributes selected by all automobile drivers are considered and the points in a Cartesian space statistically aggregated, they will form a cluster of points representing the range of attributes of automobile drivers. Similarly, a second cluster of points can be considered that consist of the preferred attributes for a park-and-ride system. Multiple discriminant analysis can be used to assess whether or not the means of the two clusters are statistically separated. If the two clusters replicate statistically two distinct modal groups, then whether or not the preferred attributes of a given individual are associated with the car-driver cluster or with the park-and-ride cluster can be determined. In this way, the effects of changes in attributes in a transportation corridor can be assessed if it is assumed that commuters have a clear perception of the alternatives available and that they in their perception and behavior act with economic rationale. In other words, they attempt to minimize their travel dissatisfactions.

This method was used to test the significant attribute changes brought about by the introduction of a park-and-ride facility that would cause a modal shift to the new facility. In other words, the approach was used to systematically investigate the reasons certain individuals shifted to the new facility. The model analysis was supplemented by a conventional attitudinal scale to test its validity.

MODAL SHIFT DUE TO PACIFIC NATIONAL EXHIBITION PARK-AND-RIDE FACILITY

The Pacific National Exhibition (PNE) park-and-ride service was introduced by the city of Vancouver and British Columbia Hydro on March 3, 1972, to service one of the most heavily used commuter corridors in the region. Agreement was made between the city and the PNE Board of Directors to use one of the exhibition parking lots as a park-and-ride terminal. Buses leave the parking lot terminal at 10-min intervals from 7:10 to 7:55 a.m., 5-min intervals to 8:10 a.m., and 10-min intervals after 8:10 a.m. The terminal is a covered stop, and the bus is express to the edge of the central business district and then follows the regular city routing. The service is also express from the same point at the edge of the CBD in the afternoon rush. The terminal parking lot is 5 miles (8 km) from the high-valued corner of the CBD, and 3 miles (4.8 km) of this is express. Buses load and unload in a bus bay centrally located in the parking lot.

The complete capital cost of the facility, including three new deisel buses and a covered bus stop shelter, was about $140,000. Vancouver provides an annual subsidy of $10,000 to the PNE in lieu of lost parking revenues.

Patronage grew quickly during the spring of 1972, leveled off in the summer at 635 daily average passengers inbound, and continued to increase to a plateau of about 900 average daily morning passengers and about 600 cars left in the lot (Figure 1).

On Friday, April 7, 1972, an on-board passenger survey (Figure 2) was made to determine why patrons used the facility and to find out some of the reasons for their shifting from their cars. Two hundred and sixty responses were received, about 48 percent of the morning rush hour patronage. Patrons were asked to fill in a questionnaire on the bus during the express portion of the trip. All answers were confidential.

The survey showed that over 77 percent of the patrons drove to the parking lot, 11 percent were driven, 10 percent walked, and 2 percent took the bus or some other mode. Almost 93 percent walked from the bus to final destinations. At least 38 percent of all patrons had been car drivers, 8 percent were car passengers, 21 percent were bus riders, and 33 percent used other modes including park-and-ride facilities. At least 12 percent of the patrons switched from a previous bus mode to the car-driver mode for the trip to the park-and-ride facility.

About 2.8 min in overall travel time were saved, walking times were decreased by about 1.2 min, and the cost was about the same both before and after the service (Table 1). The park-and-ride service had no dramatic advantages on the mean values except for the initial travel time before boarding the vehicle. When the standard deviations are taken into account we conclude the park-and-ride service is close to previous service levels.

Note the relatively long trip length for the park-and-ride patrons. Total vehicle travel time, on the average more than 40 min, is shown in Figure 3. Total pedestrian

Figure 1. Patronage trend.

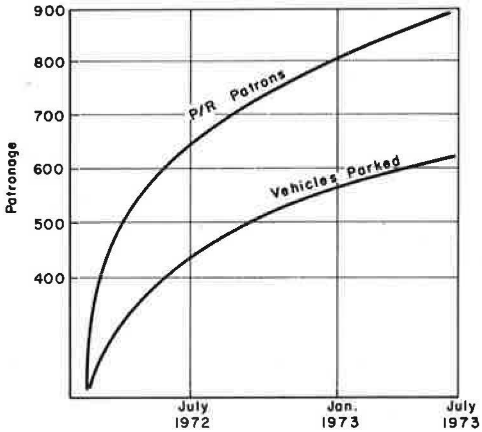

Figure 2. Park-and-ride planning survey questionnaire.

1. What is the purpose of your trip today?
   (a) work ☐ (b) personal business ☐ (c) shopping ☐ (d) school or university ☐ (e) other ________ (specify)

2. At what address did you begin your trip today? ________________ (street address and municipality)

3. To what address are you going? ________________ (street address or nearest intersection)

4. By what means did you get from the start of your journey to the Park-Ride bus loading area?
   (a) walk ☐ (b) car driver ☐ (c) car passenger ☐ (d) bus ☐ (e) taxi ☐ (f) other ________ (specify)

5. How will you get from the Park-Ride bus to your final destination?
   (a) walk ☐ (b) bus ☐ (c) taxi ☐ (d) other ________ (soccify)

6. We would like you to estimate, as closely as you can, the following details about your complete journey today. (If you don't know the answers please write in "D.K." and continue.)
   (a) total travel time of your journey from beginning to end ________ minutes.
   (b) total travel time to get from your home to the Park-Ride bus ________ minutes.
   (c) time usually spent travelling on the Park-Ride bus to where you get off ________ minutes.
   (d) usual walking time from Park-Ride bus to final destination ________ minutes.

7. How did you make this journey before you began to use the Park-Ride bus?
   (a) all the way as a car driver ☐ (b) all the way as a car passenger ☐ (c) all the way by bus, no transfer ☐
   (d) all the way by bus with a transfer ☐ (e) by both car and bus ☐ (f) other ________ (specify)

8. Now, we would like you to estimate, as closely as you can, the following details about this same journey before you began to use the Park-Ride bus. (If you don't know the answers please write in "D.K." and continue.)
   (a) usual travel time from beginning to end of trip ________ minutes.
   (b) usual walking time from your home to a regular bus, if you used the bus ________ minutes.
   (c) usual walking time from car or regular bus to your final destination ________ minutes.
   (d) usual parking cost, if you drove your car (if no cost write in "0") by day/or ________ dollars.
   by month ________ dollars.

9. Why did you switch to the Park-Ride bus? Please indicate the importance of each of the reasons below.

	Very Important	Important	Neutral	Unimportant	Very Unimportant	Not Applicable or Don't Know
(a) makes trip faster	☐	☐	☐	☐	☐	☐
(b) avoids parking cost	☐	☐	☐	☐	☐	☐
(c) reduces walking	☐	☐	☐	☐	☐	☐
(d) buses more frequent	☐	☐	☐	☐	☐	☐
(e) reduces strain of driving	☐	☐	☐	☐	☐	☐
(f) help solve City traffic problem	☐	☐	☐	☐	☐	☐
(g) other ________ (specify)	☐	☐	☐	☐	☐	☐

10. In order to correlate results would you please tic the appropriate square below.
    Sex: (a) male ☐ (b) female ☐ Age: (a) 0-16 ☐ (b) 17-25 ☐ (c) 26-40 ☐ (d) 41-60 ☐ (e) 60+ ☐
    Household Income: (a) under $6000 ☐ (b) $6-8000 ☐ (c) $8-10000 ☐ (d) $10-12000 ☐ (e) $12-14000 ☐
    (f) $14-16000 ☐ (g) over $16000 ☐

11. In the space below please suggest any improvements you would like to see made in the Park-Ride service.

travel time is shown in Figure 4. About one-half of the patrons live within 5 miles (8 km) of the terminal. A substantial proportion (10 percent) live more than 20 miles (32 km) from the terminal.

The socioeconomic makeup of the park-and-ride patrons showed that 58.6 percent were females, 67.9 percent were under 25 years old, and almost 30 percent were between 26 and 40 years old. The median income was just under $10,000/annum. Over 25 percent of the sample was in the $10,000 to $12,000 income category.

My main concern in this paper is with the characteristics that caused automobile drivers to shift modes. Therefore, those who were not previously car drivers were removed from the sample. This left a sample of 97 or about 40 percent of the park-and-ride patrons. The propensity model was used to attempt to determine why drivers shifted modes.

Table 2 gives the means of the travel characteristics of the group as car drivers and as park-and-ride patrons. For former automobile drivers, the overall travel time was increased slightly by the park-and-ride system. As expected, travel time at the destination decreased by about ½ min. The cost of the trip dropped from an average of 82 cents for parking to 50 cents for the park-and-ride system.

When the model was tested for variable significance it showed that only the cost variable was statistically significant in separating the all-automobile commuters from the park-and-ride patrons.

The follow-up direct questions about what was important also support this finding (Table 3). Respondents were asked to indicate on a five-category Likert scale the relative importance of several reasons for shifting to the system. The categories were weighted from very unimportant to very important. In this way median values were calculated for each of the attributes and for some that were included to assess other, less quantifiable, reasons. The results show that, in this case, a reduction of the parking charge was the largest factor in the shift; the next was reduction of the strain of driving. These results are based on a park-and-ride facility that provides very little, if any, savings in travel time for the average motorist using the facility. If the park-and-ride facility provided substantial travel time savings, travel time savings would appear as a more important factor than is indicated in Table 3. The validity of this hypothesis was assessed by comparing the results of this study with results from a different commuter corridor.

COMPARISON OF TEST RESULTS

The previously tested corridor served the North Shore communities in metropolitan Vancouver that have a combined population of 107,000 (4). The data were based on a sample of 465 automobile commuters to the CBD between 7 and 9 a.m. on a weekday morning. The subsample was part of a larger sample reduced by editing out those who needed a car at work and those who said they would not shift mode regardless of the alternatives provided. The remaining sample of automobile commuters were asked to indicate, on a scale, the level of service they would require to shift from automobile commuting to a hypothetical park-and-ride facility. The assumptions about the hypothetical park-and-ride system were as follows: (a) The parking terminal would be remote from the CBD, and (b) patrons would walk from their vehicle to a sheltered bus stop, board an express bus, be deposited within two blocks of their destinations, and be guaranteed a seat.

This analysis showed that a substantial shift would occur if mean travel time were decreased by about 5 min. Total out-of-pocket expenses would have to decrease, but not substantially. The overall walking time from the parking lot of the park-and-ride station to the bus compared with the existing time at the residential end of the journey would have to be about 2 min. This implies that drivers would tolerate this amount of walking at the residential end of the trip if other desirable characteristics were provided. One characteristic that shows up dramatically in the study is a great increase in the frequency of public transit vehicles needed within the park-and-ride system com-

Table 1. Change in mean travel parameters for all patrons before and after introduction of the PNE park-and-ride facility.

Variable	Before	After	Standard Deviation
Total travel time	43.48	40.68	14.41
Residential travel time[a]	2.64	18.82	11.78
Destination travel time	4.76	3.56	2.60
Out-of-pocket expenses[b]	0.44	0.50	0.00

[a]Travel time to major vehicle (car or bus before and to park-and-ride bus after).
[b]Parking cost before and park-and-ride fare after.

Figure 3. Vehicle travel time distribution.

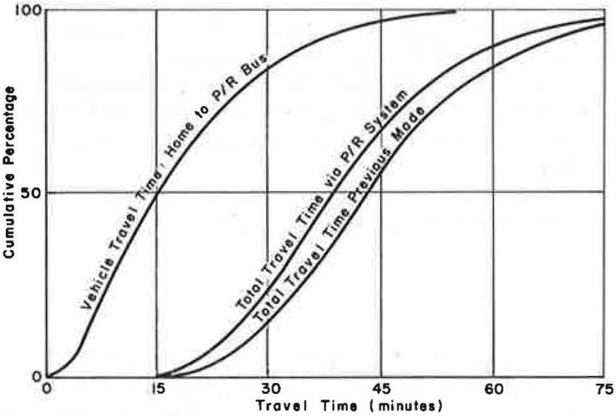

Figure 4. Pedestrian travel time distribution.

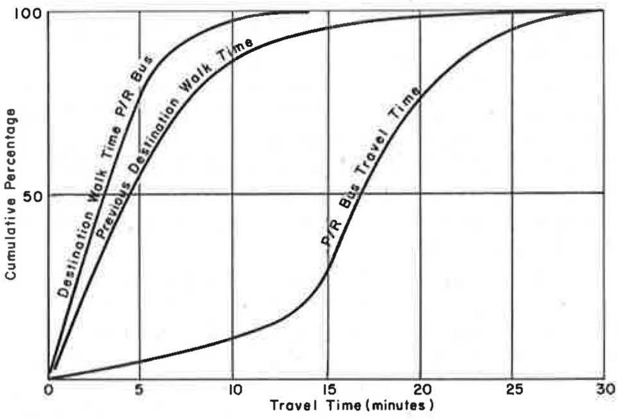

Table 2. All automobile and park-and-ride attribute means.

	Group Means	
Variable	All Automobile	Park-and-Ride
Total travel time	42.7	43.1
Destination travel time	4.1	3.5
Out-of-pocket expenses	0.82	0.50

Table 3. Importance of reasons for automobile drivers to shift to park-and-ride system.

Reason	Median Values[a]
Faster trip	2.67
No parking cost	4.07
Less walking	1.89
Buses more frequent	1.97
Less driving strain	3.82
Less traffic congestion	3.63

[a]Based on Likert scale: 1 = very unimportant, 5 = very important.

pared with the existing frequency of buses. The average car driver who is a potential shift patron would require about a 4.5-min headway between buses compared with the more than 17 min he or she has currently. This is close to the 5-min headways provided at the successful PNE facility.

OBSERVATIONS FROM STUDIES AFFECTING PARK-AND-RIDE PATRONAGE

Sample Validity

The two studies were done on different population samples and each, in its own way, may have had inherent characteristics that would tend to affect the results.

The North Shore sample was from an affluent population that has status occupations and a high incidence of car ownership but that is apparently positively oriented to transit. It is precisely these people who make up a fairly large proportion of the transit patronage from the North Shore to the CBD.

The PNE sample was biased toward the low-income groups of the population. This may have had something to do with the relatively high incidence of shift.

Parking Charge as a Factor

The North Shore study showed that park-and-ride system costs should be about the same as the existing parking cost. This conclusion is further emphasized because the parking cost of the sampled commuters was relatively low. About 30 percent of commuters parked free, and over 50 percent paid less than $10 per month or 50 cents per day. Therefore, any park-and-ride service would need to be fairly low cost to be patronized, and this would probably require free parking as is the case at the PNE site. It appears clear that commuters will pay only what they pay currently.

The parking charge avoidance is the main factor for the model shift in the case of the PNE study. This again attests to its influence in creating a modal shift.

This points to one fairly solid conclusion: A park-and-ride system must provide free parking or cost very little. This implies that a successful system probably would need to be subsidized for the procurement and operation of parking arrangements. This assumes that subsidized park-and-ride operations will increase social benefits or minimize social costs over the prevailing system. The degree to which these facilities should be subsidized can only be determined after social accounting of various transportation systems serving the CBD has been done.

It was found in these studies that walking distances and parking charges are complementary. Commuters will trade expensive parking spots for greater walking distances. It was shown by the North Shore study that about a 2-min walk time in the parking facility would be tolerated. If the total walking within the system (i.e., at the terminal plus the downtown distribution) is kept to 5 or 6 min, it appears that the system will be accepted by motorists. This finding is supported by other studies of parking and walking trends (5). More definitive data might also show that walking as a factor depends to some degree on climatic conditions.

Line-Haul Frequency as Factor in Modal Shift

The North Shore commuters indicated they wanted a 4.5-min frequency on the average. The successful PNE system provided 5-min frequency during the rush peak and 10 min at other times. This appears to be an important consideration in designing a park-and-ride system, and a 5-min frequency appears to be necessary.

Comfort as Factor in Modal Shift

Little is known about the level of comfort desired in any system although it appears to be important. The PNE patrons for example would wait for a later bus (5 to 10 min later) rather than board a full bus. Since discomfort is a function of the time of being uncomfortable, I suspect that for any significant trip length patrons must be able to be seated. (A second park-and-ride facility in the region was placed at the middle of a regular bus run, and a potential park-and-ride patron would have to stand for the trip downtown. This appears to have had a noticeable effect on the patronage of this facility.) Sheltered stops are also probably necessary.

Trip Length as Factor in Modal Shift

Both of these park-and-ride facilities would be defined as remote services by the breakpoint between remote and peripheral lots that is located 3 miles (4.8 km) from the CBD (3). Both facilities would necessitate lengthy trips by car (for North Shore commuters the mean is 31 min; for PNE commuters, 43 min). The travel time savings by the service are small for each group. However, it is obvious that the PNE facility is providing good transportation services for suburban commuters who may be attracted to it to avoid the relative congestion and parking problems they would otherwise encounter in the CBD. It is interesting that an express bus service has been initiated that serves the same market area and that has had no apparent influence on the park-and-ride patronage. This and the excess parking capacity in the system imply that market penetration for the PNE service is complete.

Although remote park-and-ride operations usually depend on a substantial saving in trip time to attract patrons, it appears that travel time savings in the case of the PNE facility are not critical to its use. This may be due to the location of the facility rather than strictly a demand factor in that it provides good access from a freeway.

POLICY IMPLICATIONS AND CONCLUSIONS

The overall objective of transportation policies should be to increase public interest benefits while social and economic costs are decreased. This implies a socially optimal modal split of transportation demand to the CBD or what is commonly referred to as a balanced transportation system. Current interest among transport planners with respect to the means of achieving this objective is to reduce automobiles and increase the use of transit. The introduction of a multimodal park-and-ride system into a transportation corridor appears to be a valid method of reducing the number of cars entering the CBD. (The estimates of diversion to the hypothetical park-and-ride system analyzed here for the North Shore may be as high as 15 percent of the corridor car commuters if the proper service is established: The PNE service is keeping a substantial portion of the 600 vehicles now parked at the site per day from downtown streets. Of course some of these parked vehicles are related to the fact that some people who now use a car to get to the park-and-ride facility were formerly bus users.) If the proper combination of walking distances, shelter design, bus frequencies and service characteristics, adequate free parking, and a similar or reduced overall travel time were provided, some motorists might shift modes (at least until the resultant reduction in congestion encourages commuters to again begin to use their cars). Parking pricing policies in the CBD would help remove worker parking from the CBD core to the fringe area.

These findings indicate the need for parking policies to be designed around several basic criteria. First, parking must be an integral part of the transportation system. Because roads and streets are public resources and there appears to be a connection between transportation services and the modal split, it follows that investment decisions about roads and streets should include parking supply and pricing considerations. This and other studies tell us that, if municipalities can exert sufficient control on parking supply and pricing policies, the demand for the use of roads and transit may be adjusted to meet modal split objectives. This has been attempted in Vancouver by means of subsidy to provide free parking for users of the PNE parking facility. If this subsidy were combined with a parking tax or higher rates at CBD lots, the effect on the shift to park-and-ride facilities would likely be increased substantially. This might be accomplished in Canadian cities such as Vancouver by enlightened operations of quasi-public parking authorities.

Second, however, any attempt to alter modal split needs to include incentives for the use of transit. As a minimum, buses must be at least partially express, frequency must be high, and all patrons must be able to be seated. In Vancouver, buses are owned and operated by the senior provincial government, and it is possible, although difficult, to achieve coordination between parking policies and transit policies. It appears that this is a factor in the success of the PNE operation. In this way public policies can be used as instruments to adjust and plan modal split. Again, however, a full awareness of the need to produce a balanced system is required so that the provision and promotion of transit services are not counterproductive. It may be that, instead of achieving a new modal split, transit policies may encourage abandonment of certain activities from the CBD.

Third, a change in the parking rate structure, the addition or deletion of spaces, or perhaps a change in the zoning bylaw can, under usual circumstances, be implemented reasonably quickly, and the results can be monitored. Line-haul capabilities can also be adjusted by new schedules and route configurations up to the point at which a substantial increase in fleet size is needed. In this way, objectives can be met in incremental steps with, largely, noncapital investments.

Operational adjustments such as rate increases, a parking tax, rate structure controls, and minor investments in facilities are more or less reversible. Parking lot operation is considered as a holding use of land, in which a parking lot becomes a temporary revenue producer awaiting changeover to a more profitable use. Therefore, the temporary nature of parking operations could, under the right circumstances, be used to advantage by testing operational changes without large capital commitments.

Policy options aimed at parking facilities, however, face some barriers to successful implementation of modal shift. This study has shown that many car drivers park free. Therefore, rate structure changes may not affect these people significantly. In addition, it is probable that most of these employees have sufficient leverage to demand on-site parking, thus also effectively making themselves immune from location policies. There are also people who use their cars during the day and would not, in any case, be able to shift. These two groups represent the irreducible minimum car population in the CBD.

ACKNOWLEDGMENTS

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ALTERNATE USES OF A BUS STOP AT A MODAL TRANSFER POINT

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In theory, urban bus stops are for the exclusive use of buses. Practice shows that many different vehicles use the bus stop for a variety of purposes. This project examines the nature of these alternate uses and their effects on bus and traffic operations. The method used was the limited case study. A single, busy bus stop in Brooklyn, New York, was observed during both peak and off-peak periods. It is along a major arterial with commercial strip development where parking is allowed. The bus stop is at a rail rapid transit station that is a link to the Manhattan central business district. Data were collected by means of time-lapse photography. The findings indicate that the alternate uses of the bus stop increase the efficiency of the use of the curb. Bus operations benefit through the reduction of bus dwell times, and the increase of delay to traffic is minimal. The nature of alternate operations does not tend to be inherently unsafe.

•ALTHOUGH bus stops within a city are generally set aside for the exclusive use of the bus, even a casual observer will notice that, in practice, the bus stop actually has many alternate uses. The bus stop becomes a convenient open space in the crowded urban area for people to store vehicles to conduct their business. Drivers enter the bus stop with their automobiles to drop off or pick up passengers or perhaps to quickly purchase a newspaper or mail a letter. Commercial drivers see the vacant curb along a bus stop as an ideal place to park their vehicles for a delivery, and taxicab drivers use the space for the exchange of passengers.

Several questions about these alternate uses naturally arise. First, how is the bus stop used? The actual alternative uses of the bus stop must be determined. Such factors as vehicle type, duration of stay, location along the bus stop, and trip purpose need to be known to understand exactly how a bus stop is used. Patterns of use stratified by these and other variables need to be identified if they exist.

Second, and more important, what is the effect of these alternative uses on regular bus and traffic operations? When other vehicles use a bus stop, do these uses represent an interference with normal bus or traffic operations, or are they a more efficient use of the curb? The effect of each group of users on bus operation, if any, must be separated and determined from the others. Perhaps there is only a single group of users that adversely affect operations. It is expected that this study will give some insight into the effects of the alternate uses on bus operations.

The method of study for this report was the limited case study. A bus stop representative of a busy urban location with a large number of alternate uses was selected. The bus stop is an interchange point with the New York City Rapid Transit System and is along a major arterial with commercial strip development. There is a newsstand across the sidewalk from the bus stop.

Data were collected by time-lapse photography during a morning peak period, an off-peak period, and an evening peak period. Although the scope of the study was limited to the observation of a single bus stop, the location was selected because of its heavy use, and different times of the day were studied to determine if patterns found varied as the time of day varied.

DATA COLLECTION

Equipment

A method is needed that allows for repeated observation of an activity. The nature of the operations is such that all the characteristics used cannot be recorded at once by one observer. Since a large field crew was neither available nor desirable, the decision was made to collect data through time-lapse photography.

The equipment consists of a standard super 8-mm motion picture camera with a tripod and an intervalometer capable of photographing at various speeds. The speeds selected for data collection were one frame/2.5 sec for the peak periods and one frame/5.0 sec for the off-peak period. The speed was sufficiently fast to allow the data collected to be representative of the activity at the site.

Site Selection

There are several goals to satisfy in the selection of a good site. The site must have a high level of activity and must be frequented by many buses to ensure interaction between regular bus operations and the alternative uses by a variety of vehicle types and purposes of use. This will allow categorization of the uses so that they may be properly described.

The site also should be representative of the urban area. From the possible types of locations, one should be selected that will allow the conclusions drawn from the data to be used, in so far as possible, by others in urban areas. The decision was made to observe a location along an arterial roadway with commercial strip development. It was felt that such a site is typical of many urban locations. Local streets within the central business district were not considered because the effect of alternate vehicular uses on bus operations might not be able to be separated from other traffic situations affecting bus operations.

The location selected was the northwest corner of Church Avenue at East Eighteenth Street in Brooklyn, New York (Figure 1). Church Avenue is an arterial street in Brooklyn. There are two lanes in each direction, and parking is allowed in both directions. This results in one lane of travel for each direction. The bus stop is 85 ft (26 m) long and can accommodate two buses.

The bus stop is served by the active bus route B-35, which passes in both directions. Headways during peak periods are scheduled at 3 min, and, during the midday off-peak period, headways are scheduled at 4 min. The average headways conform to schedule. The peak-period bus headways are both exponentially distributed.

The site is an interface point with a New York City Transit Authority subway station. This D subway line provides a link to the Manhattan CBD. The curb space outside the station is therefore used as an automobile and subway passenger exchange point. There is also a newsstand across the sidewalk from the bus stop, and many drivers stop to purchase a newspaper. Because of the commercial strip development, the curb also provides storage for vehicles during the midday for commercial delivery and shopping trips.

Reduction Methodology

A method for the reduction of the data to a useful form was developed. Data were recorded by operations, each of which consisted of a single-vehicle use, from the time it entered the study area until the time it left. The study cordon is defined as the full length of the bus stop by one-lane width into the street. Data were reduced with the aid of a stop frame analyzer.

This allows examination of the film on a frame-by-frame basis. The number of frames that a vehicle remained within the cordon and other useful information about the operation were recorded. After the data were reduced, processing was computer aided to make output useful.

DATA ANALYSIS

Data were analyzed to determine the answers to three basic questions:

1. What are the effects of alternate vehicular use of the bus stop?
2. What is the nature of these alternate uses of bus stops and what about these uses interferes with the bus and traffic?
3. What are the safety aspects of these alternate uses?

The new data are analyzed from two perspectives. First, data must be considered from a time-occupancy viewpoint to determine how the bus stop is occupied with relation to time. This allows a feel for the magnitude of the differing types of operations. The potential for vehicular interactions with the bus can be determined with respect to the portion of time interaction is possible.

Second, data must be considered from an operations viewpoint to determine the effect of alternate vehicular interaction with the bus. In this approach the characteristics of each operation are observed. This will allow insight into the effects of alternate use and into the nature of the alternate use.

The existing data, consisting of accident reports, will be examined for the study area. This will give insight into the safety of alternate operations.

Definition of Terms

In the data analysis there are some terms and concepts that must be defined. They are as follows:

1. The study area consists of the entire length of the bus stop by the width of one lane of roadway.
2. Operations concern the use of the bus stop by a single vehicle.
3. Dwell time is the total time spent by a vehicle within the study area.
4. Interaction with a bus occurs when a vehicle is within the study area and a bus arrives and is not stopped at the curb. If a bus arrives and is stopped at the curb, no interaction is assumed to occur.
5. Location is the position along the curb of the bus stop. Because of the land use pattern at the bus stop and the size of an automobile relative to the bus stop, the bus stop is divided into three sections. Location 1 is at the front of the bus stop, and location 3 is at the rear (Figure 2).
6. Placement is the distance from the curb in which the right side of a vehicle stops. Placement is in three categories: Placement 1 was at the curb, placement 2 was a half lane away, and placement 3 was a full lane out from the curb. This level of refinement was the most allowed by the data collection equipment (Figure 2).
7. Free choice refers to the choice of operation characteristics. If, on arrival, the bus stop is vacant, then the arriving vehicle has free choice in its operational characteristics.
8. Restricted choice occurs when a vehicle arrives at a bus stop that is occupied by one or more vehicles. The choice of operating characteristics is restricted by the presence of occupying vehicles.

Time Analysis

A time use analysis of the bus stop affords a view of the magnitude of the types of operation that occur. The categories of the bus stop are (a) empty, (b) with a sole use, and (c) with shared use. The quantity of most interest in this case is the shared-use category. This is the only category within which an alternate use of the bus stop provides the potential for interaction with bus operations or traffic operations. The results are given in Table 1.

Most of the time (an average of more than 85 percent), the bus stop was either unused or used by an alternate (nonbus) vehicle alone. Shared use accounted for an average of 6.7 percent of the total time. From a time viewpoint, this seems an insignificant amount. During about one-fourth of the time in which the bus stop was shared, there was no interaction with bus operations; a bus arrived while another vehicle was in the bus stop, but the driver still brought the bus to the curb. The result is that, for slightly less than 5 percent of the total time, alternate use of the bus stop accompanied some displacement of the bus. Aspects of this displacement are discussed later. This displacement was most evident in the morning peak period when it occurred nearly 8 percent of the time.

Each of the categories of vehicle use had differing percentages of the bus stop occupancy as the time of day changed. The bus had its greatest share of the bus stop use during the evening peak period. Alternate use was most evident during the morning peak period.

A summary of the time use of the bus stop shows that shared use of the bus stop usually represents the lowest portion of time of any of the categories of use. Interaction with the bus from a time perspective, therefore, appears to be low compared with the time in which the bus stop is free of shared use.

A time use perspective is incomplete in its ability to totally describe the interactions of types of use. If the data are examined from the perspective of the bus rather than the bus stop, the view of interaction changes from a minimal to a major nature. The proportion of bus time shared with other vehicles varies from approximately one-third to one-half. The morning peak period is the heaviest shared period, in which 54 percent of bus time is spent with another vehicle.

This result shows that a more drastic interaction is possible when viewed from the operations perspective. The time analysis has provided an overall view of the amount of interaction. The effect of this interaction of alternative uses on bus and traffic operations can be better determined from an operations analysis. An operation in this case is the use of the bus stop by any vehicle.

Operations Analysis

Examination of the effects on bus operations will deal with the concept of free versus restricted choice. Qualities of operation will first be examined when the bus arrives and the bus stop is vacant. This represents the case where factors of operation, such as dwell time and placement from the curb, are chosen free from interaction with alternative uses of the bus stop. This result will be the control group against which the interaction is measured. Restricted choice represents those times when a bus arrives and there is at least one other vehicle within the bus stop. If there is a significant difference in the measured factor between the free and restricted choices, the difference is considered to result from the presence of an alternate use of the bus stop.

Effects of Alternate Use

Bus Dwell Time

Bus dwell time is a measure of the efficiency of bus operations. The shorter the dwell time is, the better the bus operation will be.

Significant differences in dwell times were found to exist between free and restricted choices during both peak periods. In these cases, the dwell times of the buses were significantly lowered by the presence of other vehicles within the bus stop. It appears that, in terms of bus operations, the quality of operation is actually enhanced by the

Figure 1. Study area, bus stop shaded.

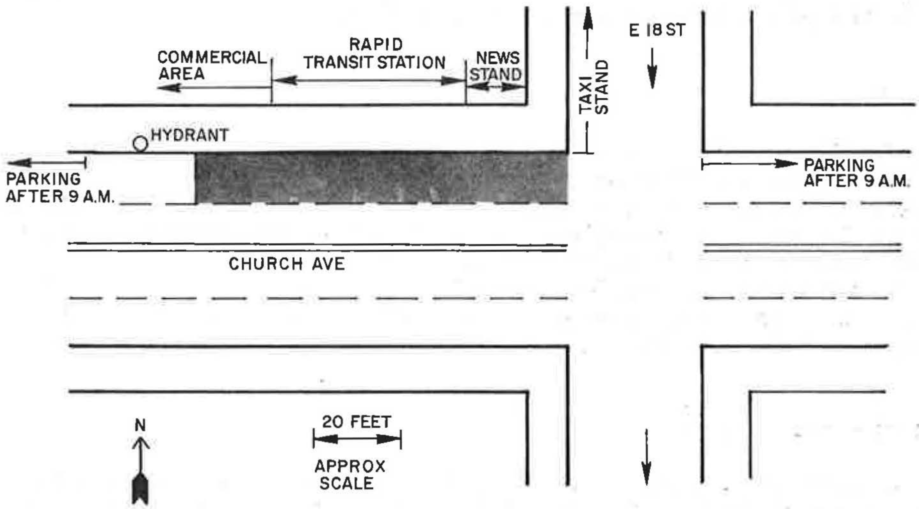


Figure 2. Location and placement in bus stop.

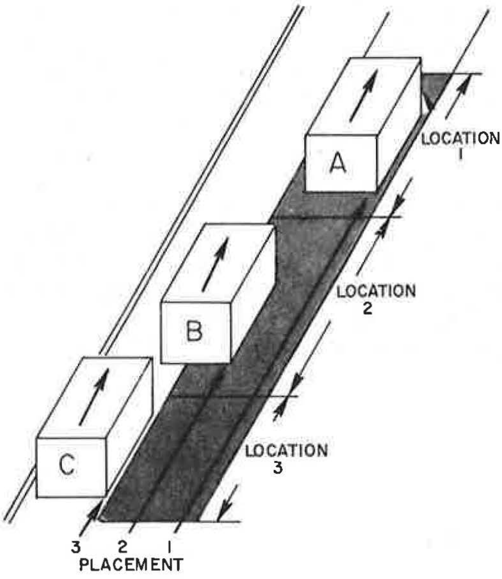


Figure 3. Bus placement versus dwell time.

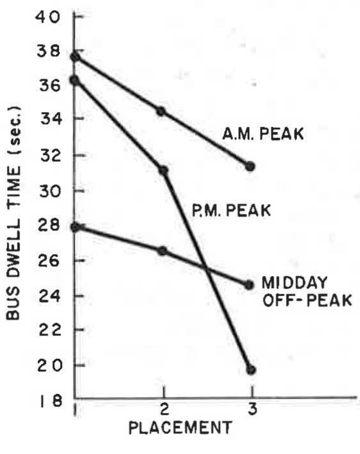


Table 1. Percentage of time period for different bus stop uses.

Use	Morning Peak	Midday	Evening Peak	Overall
Vacant	39.0	39.2	40.3	39.5
Bus only	7.7	5.4	10.7	7.9
Alternate only	44.3	50.7	42.6	45.8
Shared	9.0	4.7	6.4	6.7
Total	100.0	100.0	100.0	100.0[a]

[a]Approximately.

presence of other vehicles within the bus stop. An analysis will follow of the effects of bus location and placement on bus and traffic operations.

Bus Placement

In all cases, the difference in bus placement for free versus restricted choice was significant. Alternative use of the bus stop tends to displace the arriving bus an average of nearly half a lane into the traffic stream. Two effects of this result should be determined: the effect of such displacement on bus operations themselves and the effect of such displacement on the traffic stream.

The impact on bus operations can be measured by comparing bus dwell times with bus placement. If a relationship between bus dwell time and placement can be established, it can be used as a measure of the effect of bus placement on bus operations.

Bus Placement Versus Dwell Time

The impact on traffic operations is measured by a comparison of lane minutes of delay in two cases. The first case is a measurement of lane minutes of blockage by the bus with operations as they exist, that is, with a mix of free and restricted choices. The second case is a simulation of the lane minutes of delay caused by bus operations with only the characteristics of operation associated with free choice. The difference of delay in these two cases is attributable to the alternative uses of the bus stop.

Figure 3 shows the means of bus dwell times stratified by bus placement and by time of day. In all cases there is nearly a straight line relationship between distance from the curb and dwell time. As the bus is placed further from the curb, the resulting dwell time of that bus decreases nearly directly. This result can account, therefore, for the previous result of reduction of bus dwell time when a restricted choice was offered to the approaching bus. The conclusion is that the impact of alternate uses on bus operations tends to improve operation from the viewpoint of bus dwell time.

The reason for this reduction in dwell time appears to be related to the reduction of bus maneuvering. As a bus is placed farther out into the traffic stream, there is less impedance of bus operations. The bus driver is no longer required to move the bus out of the traffic stream to exchange passengers and then to wait for an acceptable gap to reenter the flow. The driver merely stops in place, exchanges passengers, and then continues on. The efficiency of bus operations is thus increased.

The delay calculation to determine the effect on the traffic stream is shown in the following equations:

$$\text{Delay} = (\text{dwell}) \times (\text{lanes blocked}) \times (\text{buses})/(\text{hours of observation})/60 \qquad (1)$$

$$\text{Total delay} = \text{sum of delays under consideration} \qquad (2)$$

The units of measure are lane minutes per hour. These calculations are given in Table 2 for the bus stop studied. The dwell is associated with the fraction of the number of lanes blocked. This is derived from the relationships for dwell and placement in Figure 2. The fraction of the number of lanes blocked is derived from the placement data.

As given in Table 3, the elimination of alternative uses in each case would cause a reduction in delay to the traffic stream. All of the delay, however, would not be reduced. This can be attributed to the fact that, when offered a free choice, the bus driver does not always stop the bus directly at the curb. The evening peak period offered an exception to this case because, when offered a free choice, the drivers always did place the bus at the curb. This may be due to the nature of the evening peak when the passengers are for the most part boarding the bus and the driver may be more apt to place the bus closer to the boarding passengers.

The reason for this behavior, however, is not so important as the fact that times exist when the bus stop is empty and the bus is not driven to the curb. Even if the bus is closer to the curb during a free choice than it is during a restricted choice, the result may differ from bus stop to bus stop. The quantity to indicate whether this behavior will result in a positive or negative impact on the traffic stream is the product of dwell times the number of lanes times the number of buses per unit time period. Dwell is the average dwell time of a bus at the specific fraction of lanes that it is away from the curb. The lanes are the fraction of lanes the bus is away from the curb. Thus, the traffic delay due to the alternate use of the bus stop can be measured as follows:

$$D = D_{op} - D_{fc} \tag{3}$$

and

$$D_{op} = (d_f)(b_f)(n_f) + (d_r)(b_r)(n_r) \tag{4}$$

and

$$D_{fc} = (d_f)(b_f)(n_f + n_r) \tag{5}$$

where

D = delay attributable to alternate uses,
D_{op} = total delay with normal operations,
D_{fc} = simulated delay with no alternate uses,
d = average bus dwell under D_{op} and D_{fc},
b = average number of blocked lanes under D_{op} and D_{fc},
n = number of buses per hour under D_{op} and D_{fc},
f = free choice, and
r = restricted choice.

In the case of traffic delay due to alternate use of the bus stop, the effect of alternate uses of the bus stop on the traffic stream is to only slightly increase the amount of delay. Final policy decisions would involve a weighting of factors. In the study case, the alternate uses improved bus operations slightly and decreased traffic efficiency slightly. This trade-off must also be weighed in the overall context of the amount of time within which there is an interaction between the bus and other vehicles at the bus stop.

Nature of Alternate Use

To gain insight into the nature of use of the bus stop by other vehicles, a similar type of analysis will be done. Using the free versus restricted approach would be meaningless as it is not the concern of this report to determine the interaction of alternate vehicles with other alternate vehicles. The categories of dwell, placement, and location will be examined because they describe the use of the bus stop as they interact with the bus and traffic.

Alternate Dwell Time

Dwell time of alternate vehicles will be examined to determine if there is a critical dwell time that, when exceeded, may make it more possible for a vehicle to interact with the bus.

Data were sorted into a frequency distribution of dwell times for alternate vehicles stratified by whether or not a bus arrived during the operation. The data show that there is relatively no interplay with the bus until a dwell time of 50 sec is reached. After this point, the fraction remains fairly constant until a dwell time of greater than 200 sec is reached. After this point, a bus nearly always arrived. This is as expected because the average bus headways range from 180 to 240 sec. It would appear that those types of alternate uses that exceed 50 sec begin to have an effect on bus operations. Table 4 gives the mean dwell times for both vehicle types and trip purposes.

Those operations that are associated with passenger exchange result in dwell times of less than 50 sec. They include the bus, the taxi, and to some extent, the automobile. The automobile as a vehicle type functions not only as a passenger exchanger but also as a shopping vehicle, and, as shown by Table 4, passenger exchange is the shortest of the dwell times. This indicates that the automobile has shorter dwell times when used for passenger exchange.

The evening dwell time for the passenger exchange trip purpose is somewhat longer than the rest. This could be due to an additional waiting period attached to a passenger pickup. That is, the driver of the automobile waits for the passenger to arrive at the bus stop from the transit system below. During the other time periods, passengers are generally being dropped off, and there is no additional dwell time associated with the operation.

Alternate Vehicle Locations

The location of vehicles within a bus stop may have an effect on bus dwell times and thus affect bus operations. To determine if this effect exists, bus dwell times are compiled and stratified by alternate vehicle occupancy of the curb and time of day. The occupancy patterns are then listed in the order of the associated bus dwell times and examined to see if some pattern of alternate vehicle occupancy caused a change in bus dwell times.

The results were examined to see if the trend of bus dwell time tended to increase as the occupancy shifted from front to rear or vice versa. The only discernible pattern occurred during the evening peak period when the bus dwell times tended to increase. As the rear of the bus stop became progressively unoccupied, bus dwell times were the lowest. When the rear was vacant but the middle was occupied, the dwell times were within the next lowest class. This pattern was consistent for all occupancy patterns of the bus stop during this time period. Occupancy of the rear of the bus stop would have the tendency to force the bus to be placed farther out into the traffic stream. This is consistent with the prior results of displacement from the curb being associated with reduced bus dwell times. This is also consistent with increased traffic delay.

Given that the location of an alternate vehicle may have an influence on bus and traffic operations, it is desirable to observe if the locations of vehicles tend to be related to land use. If this were the case, one might influence the effect of alternate uses on bus and traffic by changing the land use pattern of the bus stop. Figure 4 shows the location of alternate vehicles along the bus stop when there is a free choice of location. The vehicles were separated into two general classes of trip purposes: passenger exchange and commercial trips. The latter includes shopping trips and commercial deliveries.

The land uses along the bus stop are such that the entrance to the transit station is opposite location 2. Thus, if the locations were affected by land use, one would expect a tendency of vehicles for passenger exchanges to stop at location 2. Location 1 has various shops opposite it, and location 3 is directly opposite an active newsstand. One would expect commercially oriented trips to focus on these locations; this is indeed

Table 2. Traffic delay calculations for bus placement.

Category	Dwell Times	Lanes Blocked	Number of Buses	Hours of Sample	Delay (lane min/hour) Avg	Total
Case 1[a]						
Morning free	37.2	0.11	9	1.76	0.35	
Morning restricted	36.6	0.21	25	1.76	1.81	2.16
Midday free	26.3	0.60	31	4.12	1.98	
Midday restricted	26.0	0.67	37	4.12	1.90	3.88
Evening free	36.6	0	16	1.52	0	
Evening restricted	32.0	0.43	14	1.52	2.11	2.11
Case 2[b]						
Morning free	37.2	0.11	34	1.76		1.32
Midday free	26.3	0.60	58	4.12		3.70
Evening free	36.6	0	30	1.52		0

[a]Operations as they exist. [b]Simulation, bus stop always vacant on bus arrival.

Table 3. Traffic delay due to alternate use of bus stop.

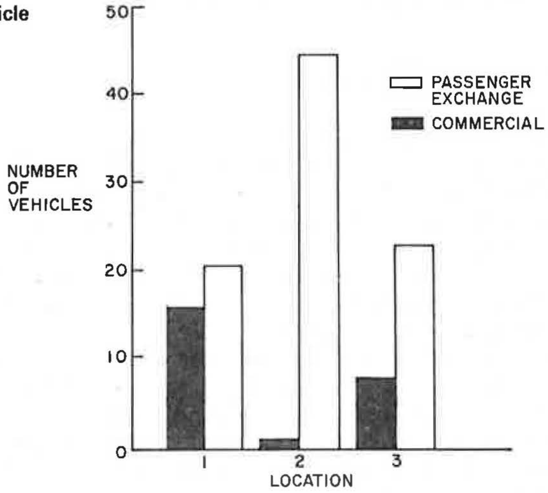
Time	Delay (lane min/hour) Case 1	Case 2	Due to Alternate Uses
Morning	2.16	1.32	0.64
Midday	3.88	3.70	0.18
Evening	2.11	0	2.11

Table 4. Mean dwell times for vehicle type and trip purpose.

Item	Morning	Midday	Evening
Vehicle type			
Automobile	48	116	110
Light truck	111	506	57
Heavy truck	320	518	–
Bus	34	26	33
Taxi	39	35	46
Trip purpose			
Passenger exchange	34	29	61
Shopping	99	176	144
Commercial delivery	244	524	72
Other commercial	298	365	–

Note: All values are in seconds.

Figure 4. Free choice of alternate vehicle location based on trip purpose.



the case (Figure 4). Therefore, location of alternate vehicles along the curb does appear to be related to land use.

Alternate Vehicle Placement

The placement tendency is such that, when drivers are offered a free choice, they usually place their vehicles at the curb. The exception was the morning peak period when 7 of the total 49 vehicles placed a half lane from the curb. Six of these seven vehicles were taxicabs.

When a restricted choice is offered an alternate vehicle, it is interesting to note whether location or placement is favored; that is, when the bus stop is partially occupied, will a vehicle place out into the traffic stream to be closer to its associated land use or will it place farther away along the bus stop to be out of the traffic stream? The trips were again separated into the commercial and passenger trip purposes. Each was considered separately. For passenger exchange, the curb-occupancy patterns examined were those in which location 2 was blocked but another location was available for use. For commercial trips, those occupancy patterns examined were those in which one or two of the commercial locations (1 and 3) were occupied and the center of the bus stop was available for use.

The result is that, when forced to choose between location and placement, the driver will usually place the vehicle out of the traffic stream and away from the desired location along the bus stop. This is good from the traffic viewpoint. Vehicles are usually stopped out of the traffic stream, and, therefore, cause a minimum of traffic interference.

SAFETY ASPECTS

Accident reports were available from the traffic department for a 2-year period from January 1970 to December 1971. There were 27 vehicle accidents at this intersection during this time period. Of these 27, 3 occurred in the area of the bus stop studied. In all three cases the accidents do not appear to be unique to the alternate uses of a bus stop. They could have occurred anywhere. The conclusion is that alternate uses of the bus stop do not tend to cause accidents.

SUMMARY AND CONCLUSIONS

This has been a case study of a single bus stop located along an arterial with commercial strip development where parking is allowed. The operation of this bus stop has been analyzed for both peak and off-peak periods. The analysis of the bus stop operation has yielded conclusions in several areas. These conclusions follow.

Shared use of the bus stop represents the least amount of time use of any of the categories. Shared use occurs when a bus and another vehicle use the bus stop at the same time. This indicates that the potential for alternate use of the bus stop to interfere with operations is minimal.

Alternative uses of the bus stop affected changes in bus dwell times and the placement of the bus from the curb. When, on arrival, the bus was occupied, the bus stopped farther out into the traffic stream than when the bus stop was vacant. However, this displacement resulted in a reduction in bus dwell time and thus improved bus operations. There is nearly a straight line relationship between bus displacement and reduced bus dwell time.

Because the bus blocked traffic for a shorter period, some of the delay to the traffic stream caused by the displacement of the bus was cancelled by the shorter dwell time. Equations were developed to measure the change in delay if there were no alternate uses of the bus stop. In the study case, alternate uses of the bus stop accounted for less than 3 lane min/hour of delay. This delay is a minimum because not all the delay to the traffic is due to alternate uses. The bus drivers do not always stop at the curb when the stop is vacant; therefore, there is some inherent blockage of traffic operations without alternate uses.

Therefore, the reduction of delay to traffic by the restriction of alternate uses is minor. This is especially true when compared with the more efficient use of the curb that alternate uses afford; that is, if the bus alone used the curb, it would be unused for better than 92 percent of the time. When alternate uses are present, the curb is unused for less than 30 percent of the time. This is of great benefit to the vehicles using the bus stop (including the bus) at the cost of a minor additional delay to the traffic stream.

Trips associated with passenger exhange had the shortest dwell time. Commercially oriented trips had longer dwell times and thus were more likely to interact with the bus. In addition, there was some indication that, as the rear of the bus stop became progressively vacant, the bus was placed closer to the curb.

Vehicles tended to locate nearest to their related land uses. This indicates that the effects of alternate uses might be controlled by controlling land use at the bus stop.

When drivers are offered a frustrated choice of curb space, vehicles will be parked farther away from the desired land use rather than be double parked closer to the destination. This is good from the viewpoint of traffic operations.

The accident reports for the study area for a 2-year period indicate that there is no special or inherent danger in the alternate uses of the bus stop.

The alternate uses of the bus stop greatly increase the efficiency of the use of the curb. There are benefits to those who use the bus stop because more curb space is available to them. Bus operations also benefit by a reduction of dwell time due to the reduced need to maneuver into and out of the traffic stream. The cost is shown to be only a minor delay to the traffic stream. In the study case, this delay was less than 3 lane min/hour.

This has been a limited case study, and further research is needed. The results obtained indicate that the presence of alternate uses of the bus stop increases the efficiency of the use of the curb. Bus operations benefit through the reduction of bus dwell times. The penalty of the alternate uses is a minimal increase in traffic delay, and the cost is small when compared with the benefits.

ACKNOWLEDGMENT

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DISCUSSION

Colin H. Alter, Maryland-National Capital Park and Planning Commission

For too many years, the use of bus stops as intermodal transfer facilities and as minor activity points has been ignored. This paper will definitely stir further research, and, it is hoped, also stir transportation planners to think about the simple, everyday problems of mobility. These reasons alone are sufficient to warrant wide dissemination of the paper, whether one agrees or disagrees with the conclusions.

There are, however, many reasons to debate the conclusions of the paper: The scope of the study appears to be excessively narrow, important research items are missing, and numerous questions are left unanswered.

The primary orientation of the paper is the physical operation of a bus stop. To that extent, it has failed to examine the needs of people. For example, safety was reviewed solely from the perspective of intervehicle accidents. The experience of pedestrian accidents is not revealed. More important, the incidence of boarding and alighting accidents to bus riders is not reported. In checking with personnel from several transit operations, I found that they unanimously agreed that boarding and alighting operations away from the curb were significantly more hazardous for riders than curb operations were. The problem is most severe for the elderly and women, but includes all riders during inclement weather. There appear to be two reasons for the problem: the increased height from the ground to the first step of the bus and moving vehicles between the bus and the curb. One of the transit operations stated that 15 percent of all claims over a 1-year period were for these types of accidents.

There are other information needs about bus stop use: What percentage of people using the bus stop were bus stop passengers? Do discomfort and decreased safety for riders boarding and alighting away from the curb equate in some benefit-cost analysis to the ease of loading and unloading at the curb for alternate uses? In evaluating this last problem, the number of people, not vehicles nor time, is the important criterion. This paper has ignored this issue.

As a separate technical issue, the amount of linear curb space necessary for a far-side bus stop for a single bus should be between 60 and 65 ft (18 and 20 m). A minimum of 6 ft (1.8 m) at the corner is required for a crosswalk. This crosswalk is the final maneuvering space of the bus. The bus itself is 40 ft (12 m) long (considering only the 50 to 53 passenger buses that are standard in most cities). In addition a bus stop must have an unobstructed 20 to 25 ft (6 to 7.6 m) (depending on the skill of the bus operator and the width of the roadway) to return to the traffic stream. Thus, the 62 ft (19 m) for the bus stop discussed in the presentation may be adequate for one bus, but not two, as asserted by the authors.

It is also necessary to explore bus operating speeds beyond the limited scope of the paper. Urban bus speeds in local service generally average between 10 to 12 mph (16 to 19 km/h). Since buses can theoretically travel at the same speed as other vehicles in traffic, a major reason for their slowness is the necessity to decelerate, manuever into the bus stop (for near-side stops) or out of it (for far-side stops), load and unload passengers, then reaccelerate to traffic flow speeds, only to repeat the process a block or two away. On congested transit routes similar to those discussed in the paper, the significant dwell time (as confirmed in the paper) is the time spent manuevering the bus into and out of the traffic stream.

The paper discussed the interference of curb operations of the bus as a benefit to bus operating times, due to the reduced need to change lanes. (In the case of this particular stop, there is no apparent difficulty in the bus manuevering out of the traffic stream to the stop since it is on the far side of the intersection.) The key problem is returning to the moving traffic lane. This problem is as much a legal problem as a traffic operations one. The solution appears obvious: Revise motor vehicle laws to grant public transit vehicles the right-of-way at all times. Nationally, it is important; in high-density urban areas it is vital if dwell times are to be reduced and passenger safety is to be improved. The conclusions of this paper are simply unsatisfactory.

It is necessary to reiterate that this paper is an important contribution because it has stimulated thought on the problem of multiple uses of bus stops. Loading and unloading problems and their accompanying dwell time delays are critical and conscious nuisances to riders. These problems are exacerbated by illegal alternate uses of the bus stop during those times that buses need to use it. The authors are correct when they urge more research in this area; also needed are the day-to-day experience of transit managers and their input.

COMPUTER-ANIMATED SIMULATION MODELS: A TOOL FOR TRANSPORTATION PLANNING

Ronald M. Baecker and Thomas R. Horsley, Computer Systems Research Group, University of Toronto

The role of computer animation in visualizing the behavior of simulation models of complex processes and systems is described. The results of a demonstration project applying this technique to transportation planning are reported and analyzed. The study involved the modeling and display of passenger flow in a subway station. It was carried out by using SIMULOGO, a new discrete-event simulation language, and ZAPP, a new computer animation system, which are discussed in the paper. Planned extensions and elaborations of these facilities to provide a comprehensive and responsive environment for transportation systems modeling are outlined.

•IN February 1974, the Ontario Ministry of Transportation and Communications awarded the first phase of a contract to the Toronto industrial design firm of Kuypers Adamson Norton Ltd. (KAN) with the intent of achieving a method of defining and evaluating those aspects of the physical environment in transit systems that affect passenger behavior. This method was to be used as a basis for potential improvements in efficiency, safety, and comfort of passenger travel. We, in the Computer Systems Research Group, were in turn asked by KAN if the computer animation techniques we had been developing could make an additional contribution to this goal. Therefore, we performed the demonstration project discussed in this paper. However, the paper attempts to go beyond this specific project and explore the role of computer-animated simulation models in transportation planning.

COMPUTER SIMULATION

Simulation is the physical or mathematical modeling of a hypothetical or real structure, process, or system. The model is a representation or imitation of that system. It usually abstracts or emphasizes particular characteristics of interest. It is often dynamic; that is, it exhibits the system's changes through time.

Reduced-scale physical models of airplane wings are placed in wind tunnels to study the effect of their shape on turbulence and vorticity. Ball-and-stick models of molecules are used by chemists for visualization purposes in research and teaching.

Mathematical models are often expressed as differential equations or as finite difference equations. They may be deterministic, in which case the outcome is completely specified by the inputs; they may be stochastic, in which case the outcome is partially determined by chance.

The implications of mathematical models are most easily derived by expressing them as computer programs. These programs are called computer simulation models (1, 2). Deterministic computer models have been used to simulate the dynamics of the solar system and of man-made satellites. A joint project of the Massachussetts Institute of Technology (M.I.T.) and the Club of Rome recently developed a computer model of world growth expressed in terms of five basic elements and their interactions: population, agriculture, natural resources, industrialization, and pollution (3). Stochastic computer models are often used to simulate job shops and computer systems.

Models facilitate the understanding of complex processes. They are used to predict and to control the future. They allow the alternative designs to be evaluated before a system is built and the implications of proposed system changes to be studied in advance. One need not make a real change to see what happens; disastrous consequences of a suggested course of action can be predicted and avoided.

Furthermore, models facilitate the rational discussion of complex processes by policy makers and planners by providing a medium in which assumptions must be made explicit so that they are accessible for debate and further analysis.

COMPUTER ANIMATION

Animation is the pictorial dynamic modeling of a hypothetical or real structure, process, or system. An animation sequence is a series of pictures that portray the system's dynamic behavior through time. Hence animation is a useful cognitive tool for visualizing and aiding the comprehension of complex processes. Since its inception, conventional animation has been plagued by the high costs and slow turnaround that result from producing 24 individual frames/sec of film. Reducing this burden is one of the goals of computer animation. Computer animation consists of a variety of techniques and processes in which the computer assists in the production of a movie (4, 5).

In one common process, the animator constructs a movie by writing a program in a language containing picture-generating subprograms (6). This program produces a magnetic tape that contains an encoded description of images and motions. Another computer then interprets the tape and draws the images on a cathode ray tube, from which they are focused onto film.

In another computer animation process, a sequence can be created and viewed in real time directly at an interactive graphics terminal (7, 8). The animator defines, either free-hand or algorithmically, the images, movements, and dynamics that make up a film; the computer immediately plays back the resulting movie for evaluation. Thus animation for the first time becomes spontaneous and immediate.

COMPUTER-ANIMATED SIMULATION MODELS

The temptation to integrate computer simulation and computer animation capabilities into one system is compelling (9, 10). Visual sequences depicting the behavior of a system could then be produced semiautomatically from the model. One could literally see the model behave. This would aid in validating the model and also deepen the modeler's intuition and understanding of the underlying system.

These animation models could be produced and used in two very different ways. First, the animation can be displayed directly at an interactive graphics console. This aids significantly in tuning the model. Various hypotheses may quickly be explored, and flawed ones rejected. Second, the sequences can be recorded on film. These hard copy visual records are useful forms of model documentation and aid further discussion, analysis, and evaluation by planners and policy makers.

APPLICATION TO TRANSPORTATION PLANNING

Computer-Animated Transportation System Models

Transportation systems consist of large collections of moving entities such as poeple, vehicles, and goods. Movements of the component entities are governed by, or may be described by, a complex set of rules or interactions. These rules may be expressed in terms of such phenomena as individual preferences, routing decisions, signaling and switching mechanisms, equipment availability, and resource allocation strategies. Transportation planners attempt to optimize these systems in terms of performance criteria such as minimizing cost, maximizing flow or system use, or maximizing passenger happiness, safety, and comfort.

Clearly such systems are complex both in space and in time. Hence computer simulation models would seem to be an appropriate tool for expressing characterizations of transportation systems, and animated representations would seem to be useful for visualizing, comprehending the structure of, and refining these characterizations (11, 12, 13).

Demonstration Project to Simulate Pedestrian Behavior in Subway Stations

We attempted to model the one-way passenger flow pattern observed during morning high-density periods in a portion of the Bay Street subway station in Toronto. This study was carried out as a small contribution to the KAN undertaking mentioned earlier in the paper. KAN gathered the data, and we used and suggested some of the initial explanatory hypotheses. In discussing the model, we intend neither to present it in detail nor to claim its validity; its use here is only to serve as a specific example with which we can present and discuss the simulation and animation techniques.

Our model deals with the following aspects of passenger movement in the station: A train arrives; passengers disembark from one of a set of doors, proceed along the platform, make a level change by a staircase or an escalator, and finally choose one turnstile by which to depart from the station.

The model is discrete and stochastic. The former implies that state changes are computed only at significant instants in the simulation. The latter implies that these state changes are in part determined randomly.

The only active components of the simulation are the trains and the passengers. Each of these is modeled as an independent process. In the context of one station, trains simply arrive, open their doors, and depart. Disembarking passengers exhibit a little more behavior, however. Their actions as they move through the station are structured in the following ways.

Passengers Are Created

Passengers are created while on the train. At that time they are assigned (based on some subjective observations of real stations) an attribute indicating their desire to move quickly through the station. In the model this is called speed even though it is used to modify their strategies as well as their basic velocity.

Passengers Exit From Train

In choosing which train door a passenger exits from, several assumptions are made. It is assumed that faster passengers will attempt to optimize their strategy and, therefore, will tend to exit through doors closest to the level change. Slower passengers are assumed to use little strategy and, therefore, are distributed uniformly across all doorways.

After choosing a doorway, the passenger requests use of that doorway. The model of the doorway is such that only two passengers may occupy it at once, and a maximum rate of 1.5 passengers/sec is achieved.

Passengers Move Along Platform

Passengers are assigned a time to move along the platform to the level change based on their speed and their distance from the level change. Although a weak attempt was made to simulate the effects of crowd congestion by using a penalty scheme based on the number of train doors ahead of a passenger, passenger-to-passenger collision avoidance was not simulated.

Passengers Ascend on Stairs or Escalator

The general assumption made at the level change is that all passengers will use the escalator instead of the stairs if the difference between escalator queue length and stair queue length is small enough. A second assumption is that faster passengers will tend to take the stairs more often; i.e., they will take the stairs even when the difference between the escalator queue and the stair queue is very small. The queues result from the specific rates that are enforced for both the stairs and the escalator.

The time for moving up the stairs or escalator is a function of the passenger's speed and the loading of the device.

Passengers Exit Through Turnstile

In the current model, passengers choose which of six turnstiles to use as soon as they reach the top of the level change. This choice is based strictly on the observed distribution at the real station, a model that yields unnatural queuing because the queue length is not a factor in the decision. A potentially better strategy, to be used in the next pass at the model, will make the choice functional of queue length and turnstile desirability, the latter being an indicator of how close the turnstile is to the passenger's most direct path to his or her destination.

Evolution of Subway Station Model

The computer simulation model was developed, and three sets of data were run through it. The results are visualized in the following films:

1. Film 1 shows 80 passengers disembarking from one train;
2. Film 2 shows 80 passengers disembarking from one train in a station configuration that assumes that there are only 3 turnstiles;
3. Film 3 shows two trains arriving 20 sec apart, one with 115 passengers disembarking, the other with 90.

The visual output from the first run pointed out some weaknesses in the model.

Film 1

Several observations were made about the first film. There is an unnatural slowing of some passengers on the platform. This can be attributed to weaknesses in the penalty scheme that attempts to account for passenger-crowd interference on the platform.

Too few people take the stairs. This can be attributed to weaknesses in the escalator-stairs choice scheme that were corrected in later runs of the model.

Too many people pass on the escalator; the effect of congestion is not adequately accounted for. This was corrected in later runs of the model. After making these corrections, we produced the second film.

Film 2

In film 2 we observed that there is unnatural queuing at the turnstiles. This effect occurs in all three runs, but is most apparent in film 2. We have already mentioned one idea, as yet untested, on how to correct this.

We then produced a third film, which led to further observations.

Film 3

We made two observations about film 3. Too many people wait for the stairs even though the queue for the stairs becomes longer than that for the escalator. This can be attributed to another simply corrected weakness in the escalator-stairs choice scheme.

Passengers who disembark close to the base of the stairs are significantly affected in their choice of escalator or stairs by the side of the platform on which they arrived. That the current model does not account for this manifests itself in unnatural cutting across the escalator queue to reach the stairs.

Sample frames from films 1, 2, and 3, in which the model is run with two trains discharging passengers, are shown in Figures 1, 2, 3, and 4. The animation technique is further described later.

TOOLS USED IN DEMONSTRATION PROJECT

Overview

The method used to carry out the demonstration project is described in what follows.

A computer simulation model is generally expressed as a program written in a computer language. The use of a special-purpose simulation language facilitates the development and realization of the model. We have developed an extremely useful, yet simple, new modeling language, SIMULOGO (14). SIMULOGO is a simulation extension of LOGO, a student programming language developed at M.I.T. and Bolt Beranek and Newman, Inc. (15, 16). SIMULOGO is described later; the Bay Street model expressed as a SIMULOGO program is in the Appendix.[1]

Execution of the computer simulation produces a time trace, that is, the details of all relevant aspects of system behavior through time. The trace is then used as input to another computer program, this one written in the ZAPP language. ZAPP, the zoom-animate-pan package, is a system for the production of computer-animated films (17, 18). The ZAPP program produces a film showing the model behaving through time.

Simulation System

SIMULOGO Design

SIMULOGO was designed as a simple but extremely useful tool that could be used by students in designing their own simulations. The premise was that more is to be learned by writing a simulation than by using one. The resulting language turned out to be more than a good student language. Because it is easy to learn and read, it is useful for real problems involving communication with non-computer-oriented designers. With relatively little instruction, a transportation planner should be able to converse directly in terms of the SIMULOGO model.

---

[1]The SIMULOGO subway station model is available in Xerox form at cost of reproduction and handling from the Transportation Research Board. When ordering, refer to XS-63, TRR 557.

Figure 1. Scale diagram of relevant aspects of Bay Street station; eastbound train arrives.

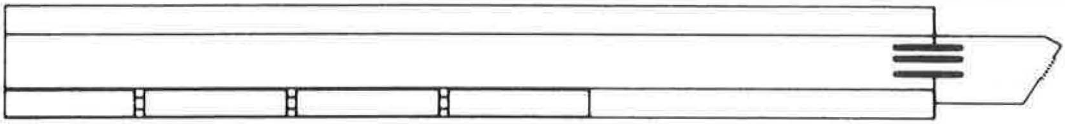


Figure 2. Eastbound train departs; one passenger has ascended escalator, others on escalator (top) or stairs (bottom) or still on platform.

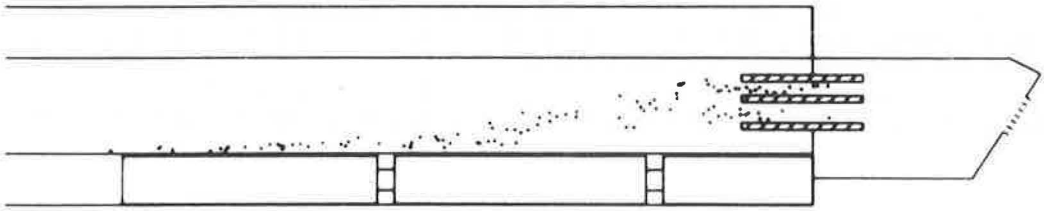


Figure 3. Westbound train arrives; first passenger is about to exit through turnstiles (right).

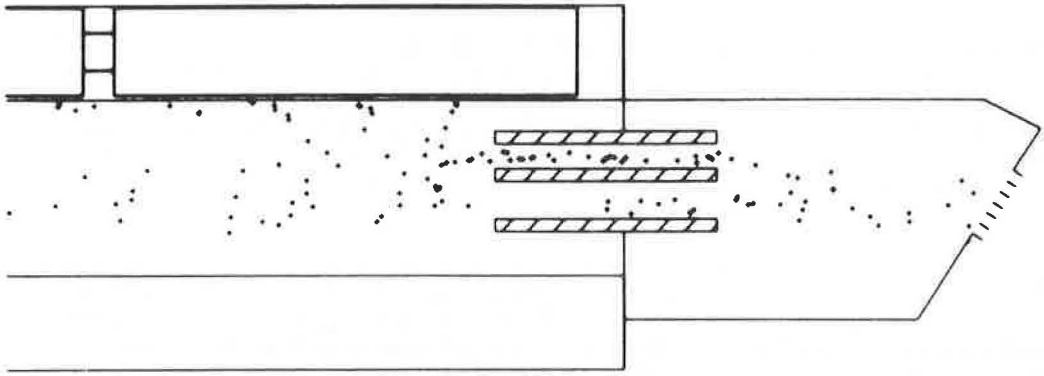
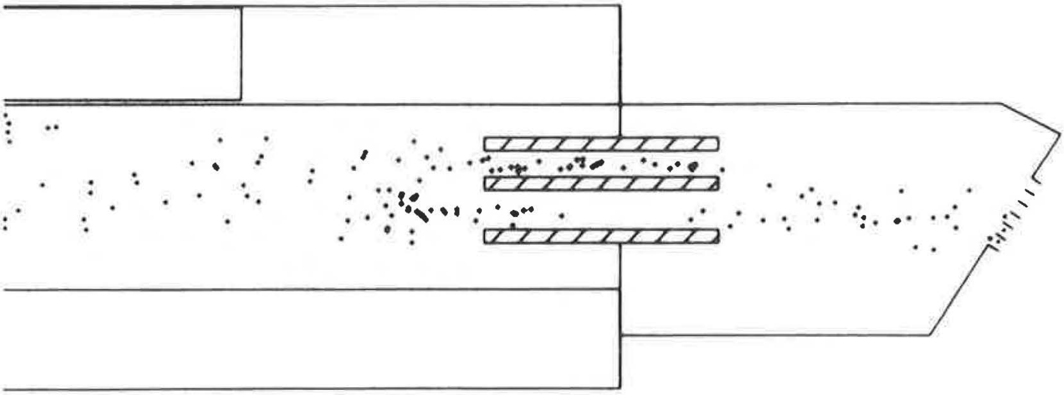


Figure 4. Westbound train departs.



Functions of LOGO

LOGO is an interactive conversational language. The user enters commands by a computer terminal; the LOGO machine executes them, carrying out the appropriate action. If the user enters TYPE 'HA HA', the computer responds by typing HA HA.

The user may also define new commands or procedures as they are called. For example,

```
TO LAUGH
10 TYPE 'HA HA'
20 TYPE 'HO HO'
```

This procedure definition extends the repertoire of actions the computer can carry out. From now on, when the user enters LAUGH, the computer responds with HA HA and HO HO. Furthermore, these new commands can be used to define still other commands. For example,

```
TO LAUGH_A_LOT
10 LAUGH
20 GOTO LINE 10
```

This procedure will continue in an infinite loop typing 'HA HA HO HO' until the escape key is hit.

LOGO procedures can have arguments and may return a value, e.g., SUM OF 5 AND 6. In this case, 5 and 6 are taken as arguments, and the value 11 is returned. Note that OF and AND are noise words and are only added for readability. The value returned by SUM may be used as an argument for another procedure, e.g., TYPE PRODUCT OF 10 AND SUM OF 5 AND 6. At the terminal, 110 is typed.

Note that, in the subway station example, several procedures are defined. TWO_TRAINS behaves like a command and is used to start the simulation. The procedure PLATFORM_TIME_DISTRIBUTION takes three arguments, DOOR, SPEED, and DIRECTION, and returns a value functional of these arguments by the OUTPUT command. Each such value is the length of time spent on the platform by a particular passenger (emerging with a given speed from a given door from a train moving in a given direction).

LOGO deals with two kinds of data, words and sentences. A word is any character string not containing a blank. A sentence is a sequence of words separated by blanks. Data are included literally in program text by enclosing them in single quotes. (Integer numbers are an exception; they are words that do not need to be quoted.) Thus 'HA', 'DOOR', and 2 are words, and 'HA HA' and '17 11 5' are sentences.

Any LOGO word may be a LOGO variable. The command MAKE performs the assignment of a value to a variable; e.g., MAKE 'ESCALATOR_LOAD' 0 causes ESCALATOR_LOAD to be a LOGO variable with value 0. To get the value of a variable, one encloses it in slashes, i.e., /ESCALATOR_LOAD/. This would return a 0.

Two concatenation procedures exist in LOGO, WORD OF, and SENTENCE OF. The former takes two words and combines them into a single word; e.g., WORD OF 'BREAKPOINT' AND 'FAST' returns 'BREAKPOINTFAST'. The latter combines words into sentences or sentences into longer sentences.

Conditional branching and looping within the program is done by a truth flag. Consider the following example taken from the object TRAIN:

```
30 *passenger starting loop*
32 .....
```

```
34 DECREMENT 'PASSENGERS' BY 1
36 TEST GREATERP/PASSENGERS/0
38 IF TRUE GOTO LINE 30
```

The function GREATERP takes two numeric arguments and returns the value 'TRUE' if the first is greater than the second, 'FALSE' if it is otherwise. The command TEST sets the LOGO truth flag according to the value of its single argument. 'IF TRUE' simply checks the truth flag and, if it is 'TRUE', executes the remainder of the statement. Thus, if the value of 'PASSENGERS' is 90 when this loop is first entered, then line 32 will be executed 90 times.

Note that comments (nonexecutable statements) are delimited by asterisks; e.g., *this is a comment*.

SIMULOGO Processes

Processes are used to simulate those things that are active in a simulation. Each passenger and train in the subway simulation is represented by its own process. Processes appear to execute in parallel and asynchronously. A process consists of a procedural statement that defines its actions and some private data that contain its attributes. For example, each subway train has certain actions that may be described procedurally and that are common to all trains. It also has some unique attributes such as direction and number of passengers. A single SIMULOGO process definition (OBJECT TRAIN) is sufficient to describe the behavior of all trains in the model. Similarly, each passenger's behavior is described by the program OBJECT PASSENGER although each passenger will be characterized by his or her own values of direction, speed, and doorway of train exit.

Processes are defined in the same way as commands or procedures. For example,

```
OBJECT PASSENGER
10  \
20   )
 .  {  SIMULOGO statements describing
 .  {  the actions of a passenger
 .   )
END /
```

Processes are created by using the primitive 'NEW'. Thus the main program (TO TWO_TRAINS) creates a station process (OBJECT BAY_STATION) and two train processes (OBJECT TRAIN). Each train in turn creates the requisite number of passenger processes (OBJECT PASSENGER).

When created, processes are passive. To become active, they must be scheduled in the agenda with an activation time. The agenda is a queue of processes ordered according to the time of next activation. In the Bay Street model, all processes are scheduled when created. For example, START A NEW 'TRAIN' 'EAST' '115' AT NOW causes the eastbound train to be activated immediately; that is, at the current instant of simulated time. However, START A NEW 'TRAIN' 'WEST' '90' AT 20 causes the westbound train to be activated 20 units of simulated time later. Active processes are made temporarily passive by using the WAIT command. These intervals where the processes are suspended correspond to regions of the simulation between decision points, such as moving along the platform or up the escalator.

Another mechanism, the RESOURCE, exists in SIMULOGO for process activation and control. A RESOURCE is simply a variable representing how many units of a certain resource are available. Two special operators manipulate these variables. REQUEST 'resource' checks if any of the resource is available. If so, it decrements the variable by 1, and the calling process continues. Otherwise, the process is suspended and enters a queue waiting for the resource. RELEASE 'resource' increments the amount of the resource available. If processes are queued up for the resource, it restarts the first one.

Resources are used in the simulation to enforce flow restrictions. The entrance to the escalator can be considered a resource of value 2 since two people can enter it at a time. The following sequence, executed by each person getting on the escalator, enforces a fixed rate of two passengers/sec:

```
.
.
.
430 REQUEST 'ESCALATOR'
432 WAIT 1
433 RELEASE 'ESCALATOR'
.
.
.
```

Randomness in SIMULOGO

SIMULOGO has several built-in procedures that behave as random variables, including DISCRETE 'sentence of numbers'. This returns an index into the histogram distribution indicated by the sentence of numbers; e.g., DISCRETE '10 80 10' returns the numbers 1, 2, or 3 with probabilities 0.10, 0.80, and 0.10 respectively. In addition, NORMAL 'mean' 'standard deviation' returns a value from a normal distribution.

Introduction to Bay Street SIMULOGO Model

Although the reader lacking extensive computer experience will not be able to understand, solely on the basis of the prior discussion, all the details of the SIMULOGO program included in the Appendix, its basic structure may be comprehensible.

The sample main program, TWO_TRAINS, first activates an instance of BAY_STATION, and this sets up most of the specific numerical assumptions embodied in one run of the model. The MAKE command at line 810 of BAY_STATION, for example, initializes the ESCALATOR resource to a value of 2. TWO_TRAINS then activates one instance of TRAIN, and then, 20 sec of simulated time later, a second instance of TRAIN is activated. These trains in turn activate 115 and 90 instances of PASSENGER respectively. (This happens at line 32 of TRAIN.) The PASSENGER program is structured to show the five phases of passenger behavior discussed previously.

Animation Technique

Although SIMULOGO is used as an interactive conversational language, the current implementation did not facilitate direct inclusion of animation capabilities. Hence a time trace of all relevant events occurring in each simulation run was output from SIMULOGO via the RECORD, WRITE, and HISTORY commands, as can be observed in the Appendix.

These data were input to a specially tailored ZAPP program that produced the movie. The ZAPP program contained all relevant aspects of station geometry including locations at which passenger events occurred, for example, the foot of the stairs. The ZAPP program carried out a graphical simulation in which it tracked the motion of each train and each passenger through time, interpolating positions between events where required. It finally produced an encoded snapshot of the modeled environment for each twenty-fourth of a second of simulated time. These encoded snapshots were transferred to 16-mm movie film by the special software that drives our microfilm recorder. The resulting film exhibits spatial and temporal properties roughly corresponding to behavior observed in the station.

CONCLUSIONS

Evaluation of Demonstration Project

The evolution of the model and the film demonstrate the sense in which a graphically mediated computer simulation system provides an environment for the rational discussion of transit phenomena and a tool for evolving a more precise understanding of them (19). Animating a model enables us to visualize intricate spatial and temporal relationships that result from a complex set of assumptions. It is difficult to imagine any other presentational technique that provides equal assistance toward visualization, comprehension, and insight.

As our understanding of the simulated phenomenon increases, this understanding is documented specifically and openly in the model and is subject to further analysis and debate. Insofar as the model can be substantiated as valid, it can then be used as a predictive tool to aid policy decisions, for example, in determining whether six turnstiles are required or three are sufficient in a particular site.

We are making no claims for the completeness or validity of the current model. Rather we stress the model's deficiencies and our ability in the simulation language to explore new hypotheses for correcting these deficiencies.

The original SIMULOGO model itself was written in about a day; simple corrections and variations can usually be expressed in minutes. For instance, the change resulting from observing that too many people wait for the stairs even though the queue for the stairs becomes longer than that for the escalator was carried out by a slight alteration to the procedure BREAKPOINT. The variations in which three turnstiles were closed were carried out by setting three of the numbers in line 610 of OBJECT BAY_STATION to 0.

This ease of use does not currently apply to variations in station geometry or to the graphical representation used. These are embedded somewhat rigidly in the animation program, and moderate changes would take hours rather than minutes. Furthermore, the separation of the simulation and the animation in two separate computer systems causes redundancy and awkwardness of expression.

Toward a Responsive Environment for Transportation Systems Modeling

Experience in the demonstration project suggests guidelines for the design of a more comprehensive, responsive, and cost-effective environment for applying computer-animated simulations in transportation planning.

Planners should be able to build a computer model interactively, obtaining feedback at every point about the syntactic validity of the formulation and about the implications of the model.

Simulation and animation should be specified and controlled in an integrated fashion in a single system. Animations of a model should be available at any time to aid in visualizing its implications. Other more traditional techniques of representing the results of a simulation, such as statistics, histograms, and graphs, should also be available.

There should be flexible and natural tools for defining and modifying all aspects and constraints, including geometrical, of the environment being simulated.

The advantage of a discrete simulation such as that obtained with SIMULOGO over a continuous simulation is that computations are made only for discrete, relatively widely spaced instants of simulated time. One saves money by sacrificing resolution in simulated time, hopefully without loss of predictive validity. Yet the animation requires an effectively continuous simulation anyway, so the modeler should always be able to control the temporal resolution and cost of each computation.

Simulations will nonetheless be costly and time-consuming. Yet many runs of a model repeat common subcomputations over and over. Methods of saving computation and restarting without recomputing are needed to facilitate cost-effective modeling.

There has been much computer science work on simulation languages but regrettably little on simulation systems and environments. The precise syntactic form in which one models a queue is not nearly so important as the set of tools with which modelers define, refine, visualize, and document their assumptions and understanding. Issues of interactivity and ease of use, lucidity and vividness of representation and presentation, and ultimately cost effectiveness must be paramount in future designs.

If these design issues are tackled responsibly and imaginatively, we predict a bright future for the tools described in this paper. They are not relevant just to subways but to transit stations of all kinds and to the flow of crowds through arenas and conventions centers, high-rise office buildings, and hospitals. The computer-animated simulation model couples one's analytical abilities as augmented by the computer and one's intuitive and visualization skills as augmented by film so that they may be used for planning and design.

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