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Addresses of Authors

Brown, Carter W., Metropolitan Transportation Authority, Planning Department, 347 Madison Avenue, New York, N.Y. 10017
Cryer, Jonathan, Department of Statistics, University of Iowa, Iowa City, Iowa 52242
Cullinan, Thomas J., Transit Program and Evaluation Bureau, Transit Division, New York State Department of Transportation, State Campus, Building 4, 1220 Washington Avenue, Albany, N.Y. 12232
du Plessis, Matt, Bay Area Rapid Transit District, 800 Madison Street, Oakland, Calif., 94607
Kikuchi, Shinya, Department of Civil Engineering, University of Delaware, Newark, Del. 19701
Kyte, Michael, Department of Civil Engineering, University of Iowa, Iowa City, Iowa 52242
Levinson, Herbert S., 40 Hemlock Road, New Haven, Conn. 06515
MacDonald, Ximena de la Barra, Metropolitan Transportation Authority, Planning Department, 347 Madison Avenue, New York, N.Y. 10017
Markowitz, Joel E., Metropolitan Transportation Commission, MetroCenter, 101 8th Street, Oakland, Calif. 94607
Richardson, Anthony J., Department of Research and Development, Ministry of Transport, Victoria, Australia
Rohrback, George, Bay Area Rapid Transit District, 800 Madison Street, Oakland, Calif. 94607
Salpeas, P. Takis, Delaware Valley Regional Planning Commission, 21 S. 5th Street, Philadelphia, Pa. 19106
Stoner, James, Department of Civil Engineering, University of Iowa, Iowa City, Iowa 52242
Teal, Roger F., Institute of Transportation Studies and School of Engineering, University of California, Irvine, Irvine, California 92717
Thompson, Theodore A., Transit Program and Evaluation Bureau, Transit Division, New York State Department of Transportation, State Campus, Building 4, 1220 Washington Avenue, Albany, N.Y. 12232
Vandebona, Upali, Department of Civil Engineering, Monash University, Clayton, Victoria, Australia
Vuchik, Vukan R., Department of Civil Engineering–Transportation, University of Pennsylvania, 113A Towne Building, D3, 220 S. 33rd Street, Philadelphia, Pa. 19104
Walker, W. Thomas, Delaware Valley Regional Planning Commission, 21 S. 5th Street, Philadelphia, Pa. 19106
Zakaria, Thabet, Delaware Valley Regional Planning Commission, 21 S. 5th Street, Philadelphia, Pa. 19106

Queens Subway Options Study Station Access Forecasts

CARTER W. BROWN and XIMENA de la BARRA Mac DONALD

ABSTRACT

In 1968, New York's Metropolitan Transportation Authority (MTA) embarked on a large subway expansion program. Two projects were started and are nearly finished in the program affecting the fast growing Borough of Queens: a new East River tunnel from 63rd Street, Manhattan; and a new subway on Archer Avenue in eastern Queens. Escalating costs and fiscal crises halted further work. These two unconnected sections, which are intended to relieve overcrowded conditions, will provide no relief unless linked in some way. The Queens Subway Options Study (QSOS) evaluated five alternative courses of action. Key evaluation criteria included the degree of overcrowding relief to existing Queens lines, and the extent to which committed capital investment is utilized. This paper contains a description of an evaluation methodology developed for this study that combines computer-based Urban Transportation Planning System (UTPS) network assignment techniques, 1980 Census socioeconomic tract data, and detailed land-use information, especially as they relate to the area of influence of proposed heavy rail transit stations. The potential for proposed stations to attract riders from overburdened existing facilities demands realistic assessment of trip origins and destinations, station access modes, and ridership. The specific travel demand characteristics for each station are needed to: (a) evaluate the options, (b) dimension the frequency of service provided on affected rail and feeder bus lines, and (c) evaluate the environmental costs of introducing a new service into developed urban environment having a complex existing public transportation network. Characteristics of travel behavior and land use within station tributary areas provided by this methodology can be used to prepare functional designs to accommodate transfer demands that minimize negative impacts and enhance development opportunities.

The 230-mi New York City subway links three of New York City's outer boroughs and that portion of Manhattan north of 60th Street to the Manhattan Central Business District, a 9-mi^2 district containing approximately 2 million jobs. Housing and population growth in the Borough of Queens, the last of the outer boroughs to develop, has outpaced subway facilities that had been completed by 1955. As a result, subway lines that link Queens and Manhattan are among the most heavily used and overcrowded heavy rail transit facilities in the United States. The 53rd Street Tunnel, the East River crossing with the highest weekday use, regularly carries more than 55,000 passengers during the morning peak hour on one inbound track.

In response to the need to alleviate this congestion, an ambitious construction program was initiated in the mid-1960s. The heart of this plan was a new East River Tunnel between Manhattan and Queens connecting with new and existing subway lines in both boroughs. Although it was eventually recognized that the entire plan could not be carried out in the near future because of cost escalation and New York's fiscal problems, construction of the 63rd Street Tunnel together with connections to two existing Manhattan lines had already begun, and is nearing completion. In Queens, however, the tunnel has not yet been linked to any existing lines, and instead terminates at an isolated station at 21st Street shortly after crossing the East River. In addition, a small segment of one of the other planned new lines, the Archer Avenue Subway and its connections to two existing Queens subway lines in eastern Queens, is also virtually complete, but not yet in use. The New York City Transit Authority (NYCTA), a constituent agency of the Metropolitan Transportation Authority (MTA), constructed these lines and also operates New York City's Subway System.

The New York MTA assembled a study team to carry out the Queens Subway Options Study (QSOS). The team consisted of members of the MTA Planning Department, including systems analysis personnel and staff urban planning consultants, as well as selected outside consultants. In order to select a preferred improvement option that would effectively utilize the facilities currently under construction and relieve overcrowded conditions that now prevail in the Queens corridor, the following five options were evaluated:

1. No additional construction
2. Queens bypass express
3. Queens Boulevard line local connection
4. Subway/Long Island Rail Road (LIRR)--Montauk transfer
5. Montauk-Archer Avenue subway connection

Under the first option, only the work now nearing completion would be finished and placed in operation, and no further construction would be undertaken. This option requires no further capital expenditures, and no new stations are involved except for opening the six under construction. However, extensive feeder bus changes are proposed to several of the new stations.

The second option represents the original 1968 proposal that was deferred when costs escalated and New York City's fiscal crisis hit. Although found to be the most costly option, it provides the greatest improvements in service. Two new stations and one rebuilt station are involved.

The third option is a short link from the end of present construction to a connection with the nearby local tracks of the overcrowded four-track Queens Boulevard Subway line. After making certain service adjustments, the local tracks have capacity available to utilize the new 63rd Street Tunnel to approximately one-half of its capacity, thus affording a meaningful degree of relief. This is the least costly of the "build" options. Although no new stations would be built, a new subway-subway transfer connection between two nearby stations is needed to restore a link disrupted by the service adjustments.

The final two options make use of the lightly used, mostly freight Montauk Branch of the LIRR. Under the fourth option, the LIRR, an MTA-owned facility, would operate service from Southeast Queens to a new under-over transfer station to be built in western Queens where passengers would change to 63rd Street subway trains to complete their journey to Manhattan. In addition to this new suburban rail-subway transfer station, six existing LIRR stations would also be upgraded. Feeder bus service would be enhanced, and some intermodal bus transfer facilities provided.

Under the last option, subway trains would operate directly over the tracks of part of the LIRR Montauk branch to a connection with the nearly completed Archer Avenue Subway. Three new stations would be built and one existing LIRR station would be upgraded, and feeder bus service would be enhanced. One of the new stations, Fresh Pond, is the example discussed in this paper. The five options are shown in Figure 1.

With the exception of the first option, each option assumes construction of new lines that would permit the integration of the new tunnel with existing Queens subway lines. The QSOS was structured to adhere to UMTA Alternatives Analysis and Draft Environmental Impact Statement (AA/DEIS) procedures in order to meet federal requirements. Because the options involve new subway services and stations that will be integrated into a complex existing system, the study objectives are broader than would be the case for a single line, new start system.

One of the most important system-wide study objectives was the need to forecast the passenger volumes that use each East River crossing. This was critical to the study because the utilization of the new 63rd Street Tunnel and the relative change in overcrowding of the parallel crossings were important criteria in option evaluation. The nature of subway service in Queens is such that the choice of Manhattan entry point is a rather complex issue. Each line ties into a unique service area in Manhattan, but the rider is generally provided with a choice of routes before leaving Queens. This choice is provided by either the use of multiple routes serving the same station (flexing), or by the provision of relatively convenient free transfers. The new routings assumed for the various options increased the range of choice to include the new 63rd Street Tunnel. Consequently, the study team had to forecast paths based on extensive origin and destination data and a complex route structure.

The other major, system level concern that influenced station use analysis is the complexity of the extensive bi-modal subway and feeder bus system that is already in place in Queens. Each new station or revised bus route will draw riders from stations or routes that are currently in use. Normally, a new transit line draws trips from the automobile mode, so the former path of the diverted trip is not a matter of concern. However, in many parts of Queens, transit is by far the dominant mode for Manhattan-bound work trips. (In some places, the share exceeds 80 percent of total travel.) Consequently, trips using the new stations are generally diverted from another station and line. Because this shift, if it results in a reduction in crowding, is desired, the study team had to closely account for every trip to measure system loading for each option.

In addition, the complexity of the transit system coupled with the rather dense development in many parts of Queens increases the importance of local neighborhood characteristics. In cases where stations are close together, a physical barrier or an unattractive land use might have a more important influence on station choice than simple walking distance. In other instances, two bus routes passing within blocks of each other might serve two totally different subway lines.

These factors determined the choice of an evaluation methodology that combined both system-wide analysis and detailed station-area analysis. The main outputs expected from it are as follows:

1. Year-2000 peak-hour forecasts of subway system use reflecting shifts in station and route loading that will result from proposed new stations,
2. Ridership estimates for each proposed station by mode of access, and
3. Identification of bus and pedestrian flow characteristics.

System volumes and station ridership forecasts contribute to a justification of the choice of an option and delineate the volume and frequency of service that has to be provided in the future subway line and the feeder bus system. The volume of each access mode has a strong influence on station design with regard to modal interchange facilities and access and fare collection location. The three outputs combined contribute to determining the extent of the physical and social impact of the location of a station in each particular neighborhood.

EVALUATION APPROACH

In order to meet the specific requirements stated previously, the study team developed an analysis approach that combined computer-based UTPS network assignment techniques with a more fine-grained, detailed analysis of each station area's physical, land use, population, and travel behavior characteristics. The key to this approach was the juxtaposition of census tracts and UTPS zones. In this way, the census tracts could be used as the basic analysis unit for detailed analysis while maintaining controls for system level network assignments based on UTPS zones. Thus, more detailed information was included in the analysis without increasing the complexity of network coding and data processing. At the same time, the battery of planning and analysis programs available in UTPS could be used for system analysis and corridor-wide summaries.

Census tracts were chosen as the minimum physical unit for this analysis, although site level land use information was used when the distribution of housing within the tract was important. Socioeconomic and travel information data at tract level were available from the 1980 Census.

The basic information that was utilized is as follows:

1. 1980 Census data at tract level
   a. Subway work trips to Manhattan
   b. Income levels
2. New York City Department of City Planning 1981 Land Use Maps
   a. Residential locations
   b. Housing typology
   c. Physical barriers to pedestrians
   d. Street patterns

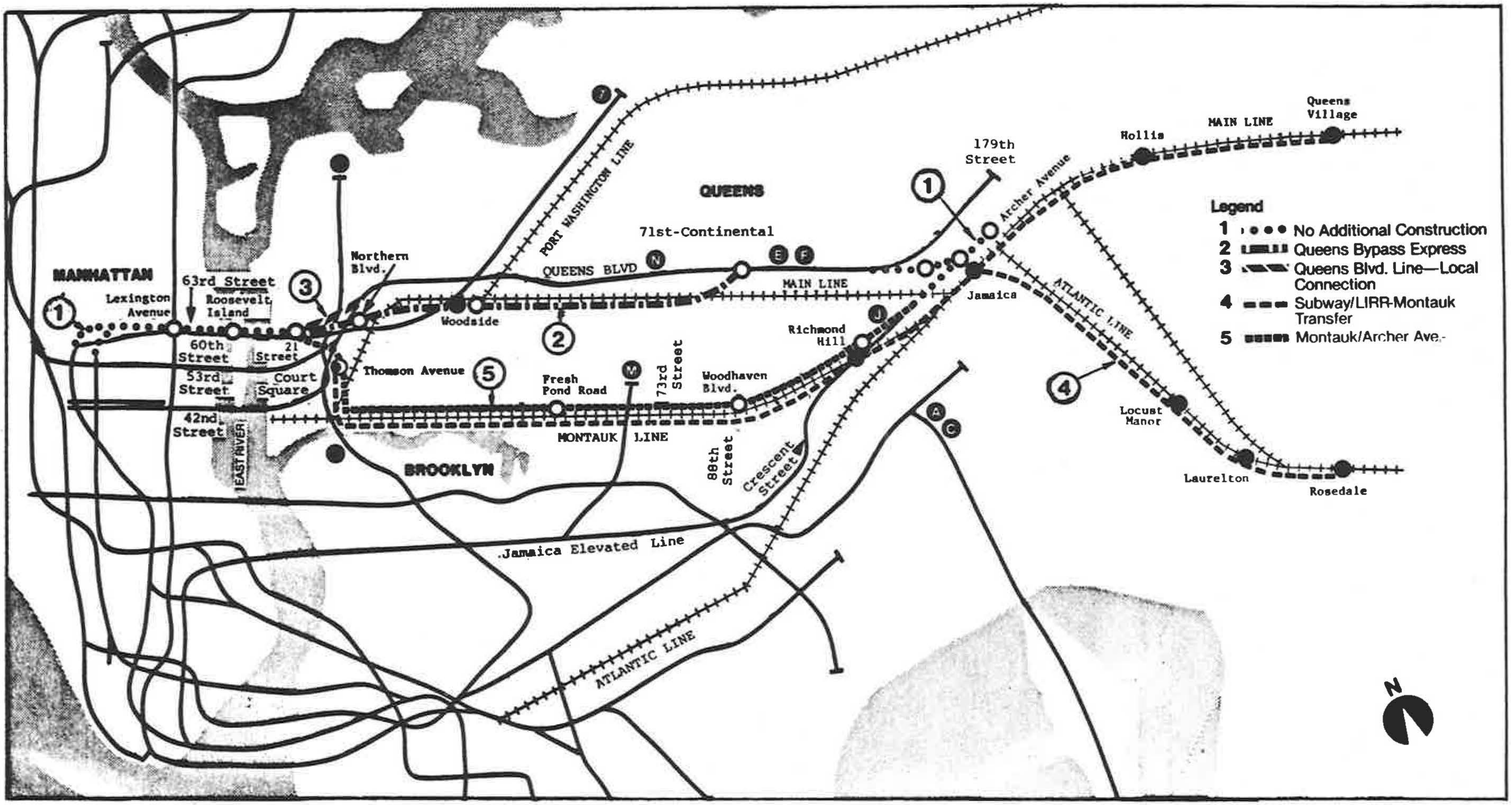

FIGURE 1 All alternatives—QSOS.

3. UTPS Trip Tables and Networks
4. NYCTA City Wide Origin and Destination Survey
5. Existing subway, bus and commuter rail schedules
6. Walking reconnaissance of the community

The City Planning Land Use Maps were adopted as a working base and all basic information was added to these maps. Census Tract boundaries and the UTPS grid were superimposed on the land use information. Existing and proposed station locations were plotted. Physical barriers to pedestrians were established. The location of trip origin location and trip densities were also plotted at the tract level. Public transportation routes for all modes available in the area were mapped on the same base. Finally, a walking reconnaissance of the community confirmed the up-to-date validity of the information and, in some cases, identified relevant new information. In this way, all basic information was visually correlated.

The analysis at the tract level is flexible and allows several simultaneous station options for each tract, even if stations may be located outside the tract. Furthermore, it is possible to assume that the tract is served by several modes of access. The share of walk access is related to the distance and accessibility to the station and the share of bus-drive access of the remaining trips is related to the future bus service availability within the tract.

Station Area Evaluation

In order to explain the station area evaluation methodology in detail, a specific case has been selected from the study area. A typical application is shown for UTPS Zone 344 for the Montauk-Archer Avenue Subway Connection Option within the Fresh Pond station area of influence. This zone constitutes a good example because it is located in an area currently being served by several existing subway stations and bus lines. Zone 344 contains the origins of most of the walking trips to the proposed Fresh Pond station. In addition, the Fresh Pond station can be expected to have the largest volume of walking trips within the Montauk-Archer Avenue Subway Connection Option, as well as the largest volume of bus-automobile trips from within its area. Some bus-automobile trips will also come from distant zones.

UTPS Zone 344 is illustrated in Figure 2 showing its relation to the Fresh Pond station and other existing stations, and to the physical barriers that impede pedestrian flow. Figure 3 shows the census tracts that are totally or partially within the zone.

The method that determines passenger volumes and mode of access to intermodal transfer facilities includes the following four phases:

- Allocation of census tract information to UTPS zones;
- Walking access determination;
- Mode allocation of nonwalk trips; and
- Year-2000 peak-hour volume projection by mode of access.

Allocation of Census Tract Information to UTPS Zones

In order to link the detailed census analysis with the UTPS network assignment analysis, each census tract segment was allocated to a specific UTPS zone. There are 17 tracts or tract segments in UTPS Zone 344. Some of them lie within two or more adjacent UTPS zones.

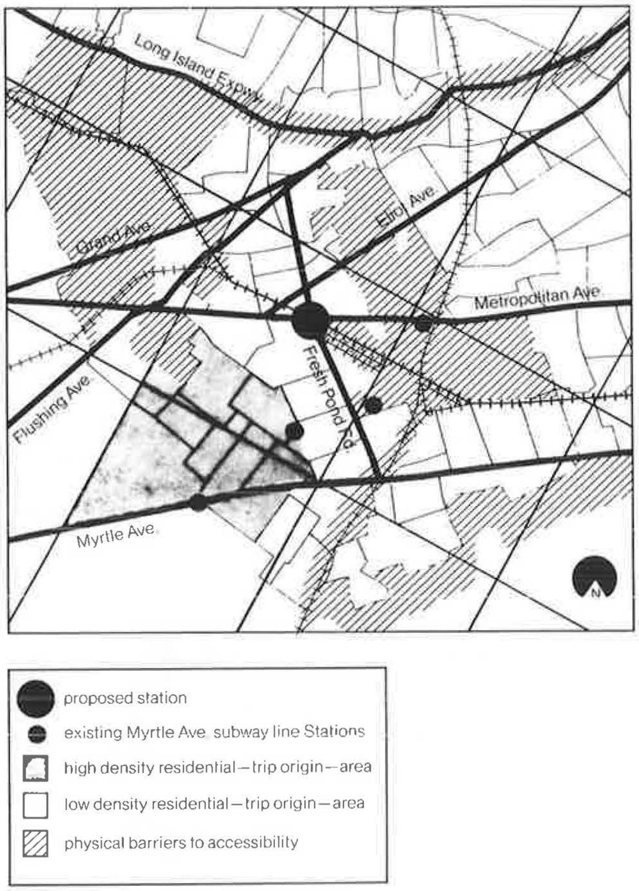

FIGURE 2 Fresh Pond station—tributary area and physical barriers.

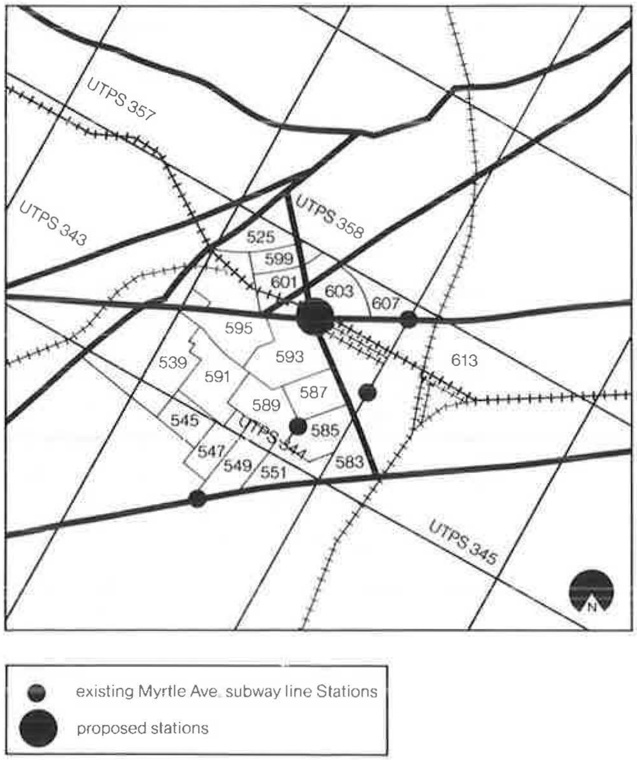

FIGURE 3 Fresh Pond station—UTPS zones and census tracts.

The data sources cited previously indicate that residential areas were generators of these trips. The land use analysis provided a good notion of densities related to housing typology. City Planning 1981 Land Use Maps indicated the following residential uses: one-family detached, one-family attached, two-family, walk-up multiple, and elevator multiple. With this information, the distribution of population within a tract could be determined. Therefore, tract allocation to UTPS zone could be conducted by considering actual resident population distribution rather than in proportion to surface area, which would have been a less accurate approach.

Walking Access Determination

1980 census tract subway trips to Manhattan were allocated by mode of access to the stations. The first mode to be allocated was the walking mode. For each census tract, real average walking distances to the station were determined. Trip origin distribution was not considered homogeneous within each tract, but was related to the actual residential distribution within it. Rather than using airline distances, walking distances were measured over the land use map that shows residential location, existing street network, and physical barriers. It was assumed that the probability that people will walk to the stations following optimal walking paths is a function of walking distances. A probit model describing this relationship was developed for the QSOS study (see Figure 4). The Citywide Origin and Destination Survey prepared by the NYCTA, was the primary source of data used to establish this probability. Only zones in Queens with characteristics similar to the study area were considered in developing this probability curve.

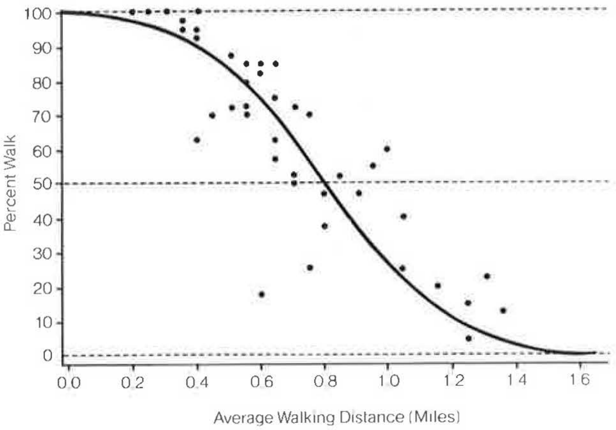

FIGURE 4 Probit walk access model.

If a tract had more than one station option on subway lines having similar destinations, it was assumed that the choice would be the nearest station. When several subway lines with different destinations were competing with the future stations, trip assignments by tract were made according to destination and time saving. In the Fresh Pond station example, the new station would compete with the existing Myrtle Avenue (M) and Canarsie (LL) lines, which are within walking distance from some tracts, and with more distant Queens Boulevard line and Flushing line stations reachable by feeder bus. Based on UTPS network and trip table values, it was determined that 25 percent of the trips would use the Myrtle and Canarsie lines to reach Wall Street areas while 75 percent of the trips had midtown destinations and would use the new station.

Allocation of Nonwalk Trips

Riders who would not be expected to walk to the stations according to the walk probit prediction because their origin was too distant from the station were assumed to use a bus or automobile to reach the station. Bus route information was combined with census tract subdivision and residential distribution in the allocation of trips to a specific bus route and station destination. The possibility of extending existing bus routes or slightly modifying them to cover more demand was also considered. Additionally, bus-automobile estimates were augmented with UTPS trips that had their origin in zones that were distant from the stations, and that the detailed method now described could not account for. The bus-automobile mode split for nonwalk trips in tracts with available bus service was made according to a model that relates the probability of automobile usage to the number of peak-hour buses serving each station. Because bus routes in the study area generally use the higher level arterial streets (freeways are extremely congested), it was assumed that automobile trips would choose the same station as bus trips. In this way, every 1980 subway work trip to Manhattan was assigned a specific station origin, a mode of access to the station, and, in the case of feeder bus, a specific bus line.

Year-2000 Peak-Hour Volume Estimation by Mode of Access

The initial allocation of trips by mode to each station was done by using tract data from the 1980 census. However, resident-based work trips could not be used for subway-system volume estimates because other trip purposes were not accounted for and no indication of time of day is included. For system analysis, the UTPS trip table and network were calibrated for the morning inbound 8:00 to 9:00 a.m. peak hour. The peak hour was used because this time period corresponds to the time of day when Queens subway riders are currently subject to extreme overcrowding. To reconcile the census work trips with peak period inbound travel, a peak adjustment factor was developed for each UTPS zone. This factor is given in Table 1 for the Zone 344 example. The 0.519 factor is typical of Queens where the dominant subway trip purpose is Manhattan-bound work travel. These peak factors were reviewed for each zone. Adjustments were made to the 1980 UTPS trip table where the factor fell outside of the expected range of variation.

Future travel for the QSOS was forecast for the morning peak hour in the inbound direction for the year 2000. First, the 1980 trip table was calibrated to reflect 1980 morning peak-hour volumes. Then, by utilizing econometric modeling techniques, the anticipated increase in peak-hour ridership was determined for the year 2000. These models established aggregate ridership controls for NYCTA rapid transit lines at the East River and western terminals of the LIRR. The forecast ridership was allocated to zones by computing zonal growth factors based on study area districts and then applying these factors to the 1980 zone-to-zone trip table. The output of this step was a detailed inventory of year-2000 travel in the study area at the zonal level.

TABLE 1 Montauk-Archer Avenue Subway Connection (Zone 344): Manhattan-Bound Workers Using Subway by Station Access Mode

		Fresh Pond Station			BMT Station		
Census Tract	Total Trips	Walk (%)	Walk Trips	Bus Trips	Walk (%)	Walk Trips	Bus Trips
601	193	75	145		25	48	
603	167	75	125		25	42	
599	53	75	40		25	35	
535	19	40	8	11			
595	252	70	176	13	25	63	
525	84	71	60	3	25	21	
539	224	29	65		25	56	103
593	465	75	349		25	116	
613	497	75	373		25	124	
587	439	75	329		25	110	
589	559	60	335	84	25	140	
591	346	65	225	17	25	87	
545	123	35	43		25	31	49
547	95	35	33	38	25	24	
549	95	20	19	52	25	24	
551	245	19	47	69	25	61	63
585	504	60	336	42	25	126	
583	83	52	43	19	25	21	
Total 1980	4,443		2,751	348[a]		1,129	215[b]
1980 PK	2,306		1,428	181		586	110
2000 PK	2,417		1,497	190		614	115

Note: PK = peak.

[a] Includes bus lines B58, B53, Q38, Q39, Q67 to Fresh Pond station.

[b] Includes bus lines B58, Q39 to BMT subway lines.

As with the peak factor, a future factor was developed for each zone. This factor was applied at the tract level so that year-2000 trips could be summarized to UTPS zone and to station of interest. It was then possible for the team to allocate year-2000 peak-hour values by census tract for each mode of access. Tract level forecasts were first aggregated at zone level for the purpose of corridor evaluation and final adjustments. Later, they were aggregated to station influence area for the purpose of station design proposals and for the evaluation of the physical and social impacts of the station on the neighborhood. Knowing the physical location of every tract with regard to stations and the existing street network, the physical impact of the demand flow for each mode could be clearly visualized.

Summary of the Zone 344, Fresh Pond Station Example

Table 1 shows the result of this methodological process for Zone 344 and all the census tracts within it, and Figure 5 shows the physical impact of the demand on the transfer area. In the case of Fresh Pond, the study team found that most of the walking trips originated from census tracts in Zone 344. In addition, some of the tracts in Zones 343, 345, 357, and 358 also generated walking trips to this station. Together, these tracts constitute the Fresh Pond tributary area. This area was also found to produce walking trips to competing stations on the Myrtle Avenue and Canarsie lines. It was estimated that the total Fresh Pond tributary area would produce 1,976 walk trips to Fresh Pond during the year-2000 peak hour. Most of these walk trips come from south and southwest of the station, where the higher residential densities are located and where the pedestrians encounter fewer physical barriers.

Bus trips to Fresh Pond and other existing stations within the Fresh Pond tributary area were also estimated in detail, allowing several simultaneous bus options for nonwalk trips from each census tract. The study team determined that the bulk of the bus trips to Fresh Pond station originated in Zone 345, which is southeast of the station, approaching the transfer from Fresh Pond Road on the B58 bus route. Other bus routes that transfer at Fresh Pond and that bring passengers from within the tributary area are lines B53, Q38, Q39, and Q67. As many as 1,500 bus transfers are expected for the year-2000 peak hour, with 1,000 of them coming from within the detailed study area and 400 from the periphery.

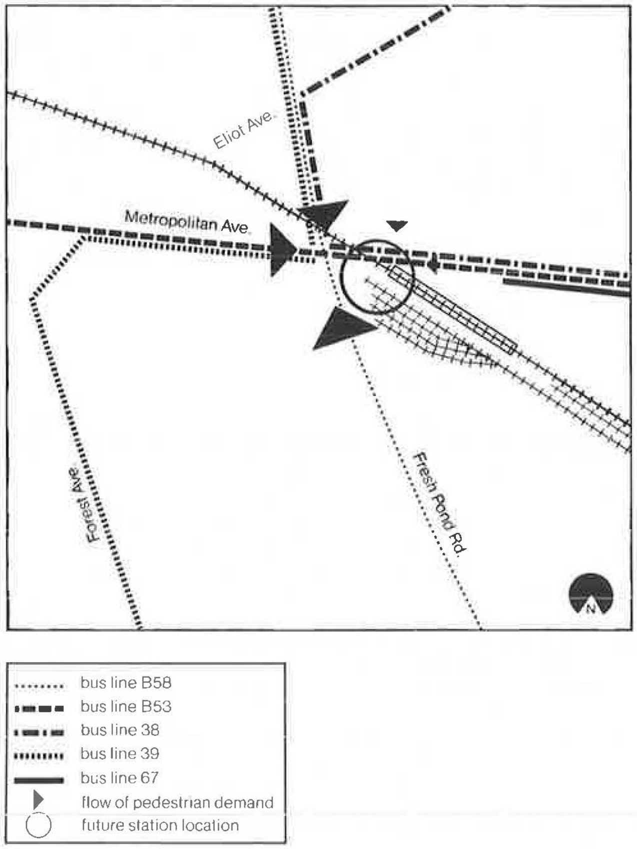

FIGURE 5 Physical impact of transfer demand.

Automobile trips to Fresh Pond station were estimated to be 500 for a year-2000 peak hour. Most of them originate from Zone 345 (southeast of the station) within its tributary area. Some automobile trips will come from the periphery, following a similar pattern to the bus trips. In all, it was established that the Fresh Pond station will have to accommodate almost 4,000 trips in the year-2000 peak hour. The tributary area will also produce bus and drive trips to Myrtle Avenue and Canarsie Line stations and to the Hunters Point Avenue station on another line.

Corridor Evaluation

The methodology described in detail for the proposed Fresh Pond station UTPS Zone 344 was carried out for zones encompassing twelve other proposed station sites. Figure 6 shows 14 of the 37 UTPS zones where station area analysis was applied. Although some station sites were unique for a particular option, other sites would be included in a number of options. In these cases, multiple forecasts were generated to take into account variations in service between options.

The detailed station area analysis was incorporated into the systemwide UTPS analysis through a two-step process. While the station analysis was

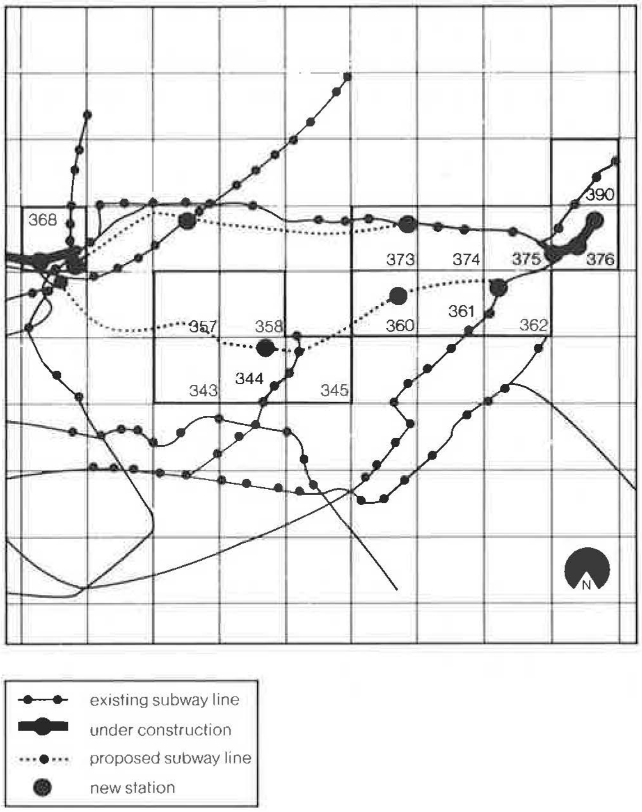

FIGURE 6 Montauk Archer Subway Connection—Detail Analysis Area—UTPS zones.

being developed, interim UTPS assignments were run for each of the five options. In the UTPS model, trips originate at the zone and are loaded onto the system at the station by means of walk links, or by bus transfer links if no station is within the zone. As was shown in the sample station area analysis, the mode of access forecasts were summarized both by station and by UTPS zone. By comparing the zone summaries to the interim UTPS runs, the study team was able to identify differences between the two techniques.

It was possible in many instances to change the UTPS walk links to reflect the more precise access measurements made as part of the detailed analysis. So, although the access link coded for a square-mile zone still represented a generalization of the expected walk trips after adjustment, the link more accurately reflected such things as physical barriers and actual distribution of housing units. In zones not served by subway stations, similar adjustments were made to bus access links. By means of such adjustments, the final UTPS assignment was brought into close agreement with the station area analysis.

In order to maintain consistency with the systemwide forecasts, subway link volumes were based on the UTPS runs. However, the mode of access determinations made as part of the station area analysis were used to establish forecasts superseding those based on UTPS techniques. In some instances, the bus access forecasts were developed by combining UTPS results with station area estimates. In these cases, where the bus tributary area extended beyond zone boundaries used for detailed analysis, UTPS bus route volumes were added to the mode of access estimates.

For the final forecasts that were used in the UMTA AA/DEIS, station, link, and line volumes were taken directly from UTPS output. By using this information, East River crossing volumes for each option were further analized to establish levels of crowding and measures of tunnel capacity utilization. UTPS output was also used to estimate passenger minutes saved for each option and the number of riders who would experience crowding in each option. The data were, in turn, used for the cost-benefit analysis carried out as part of the alternatives analysis.

The Subway-LIRR Montauk Transfer option assumed an upgrading of suburban railroad service to five existing stations in Southeast Queens. For the 23 UTPS zones making up the tributary area for those stations, the methodology used was different from the techniques described in the example. For this option, the new service would be in addition to existing feeder bus service, and was assumed to have higher fares and higher quality service, with greater speeds and more comfortable rolling stock than the four all-subway options. Because of the added number of choice items, a logit type submodal split model was used. (This model is described in greater detail in the Alternatives Analysis Technical Supplement.) As with the example zone, the census tract was the basic analysis unit, and station area measures such as walking distance to stations were developed in the same way. However, for these tracts, income level and various measures of service were explicit model input. Submode choice (and thereby station choice) was developed for each tract based on the probabilities developed from the model. Trips were then allocated to stations or bus routes as was shown in the example.

STATION AREA EVALUATION APPLICATIONS

The main purpose of the station-area evaluation was to produce adjusted travel demand forecasts by mode of arrival by census tract for each station. The objective was to evaluate the viability of proposed stations and the effectiveness of each of the alternatives in the QSOS--that is, to evaluate what service improvements could be achieved, and at what costs in terms of investment and environmental impacts.

The introduction of a new heavy rail service into an older, developed urban environment presents special challenges. The most critical interface between the new facility and existing development occurs at the station. The proposed station facility must be compatible with the urban structure already in place. For bus access, existing service patterns cannot be radically changed as a given route may serve other stations as well as other important trip generators. At the station site, local streets may be heavily used and frequently all land is developed with uses that may or may not be compatible with a transit facility. The detailed tract and land use analysis provides the planning information needed to deal with these concerns.

Impacts on the environment brought about by the insertion of a new transit facility can be both positive and negative in character. Negative impacts often can be controlled, mitigated, and even eliminated with appropriate design of the new facility and with proper design of the operating schemes.

Negative impacts that can be expected are mainly those produced by the increase in traffic activity to and from the station. These impacts were quantified for each station site as part of the detailed analysis. Volume estimates of bus and automobile trips by direction of origin were added to current traffic counts to develop measures of emissions and noise. Both traffic estimates and land use information were used to identify potential problems at intersections, bus stop locations, and pedestrian street crossings. As part of this effort, sensitive land use types such as schools and parks were identified.

The most evident positive impacts will undoubtedly be the accessibility improvements to and from the area and the potential revitalization in the station vicinity. If the new station is combined with additional needed services and commercial facilities, then the whole neighborhood may be upgraded. New development could also be programmed in locations with "soft spots" or on sites that are not fully developed.

By determining the main characteristics of travel behavior and land use for each tract in the station tributary area, the basic information needed to establish a functional design for each intermodal transfer was available. Such a design should not only accommodate flows of pedestrians, buses, and automobiles, it should also minimize the negative impacts expected from the new facility and enhance the development opportunities for the site.

The peak-hour volume forecasts are the main factor for designing these facilities. Forecasts of walk trips from each tract indicate the best location for station entrances. Estimates of expected transfers for each bus route in the area, along with existing patterns of bus stops and terminals, lead to the design of bus facilities. From this information, design requirements for curb space, layovers, turnarounds, and pedestrian crossings can be established, as well as possible modifications to route structures to improve station area circulation. For each station, the volumes of expected transfers will indicate which mode should be given priority and the nature of the design solution proposed for the station site.

The land use in the station vicinity also affects station design. Evaluations of structural condition and use led to the identification of "soft spots" where sites could be acquired for bus access roadways and other station-related uses. In other instances in which analysis showed places where bus circulation might produce negative impacts, solutions such as noise barriers comprised of vegetation were considered. Topographical features were also taken into account in the functional design and, in some cases, multilevel stations were considered to minimize impacts.

Because this was an alternative analysis study, and specific study sites might not have been included in the ultimate preferred alternative, the main use of the functional design process in this study was to develop cost estimates. However, when a preferred alternative is selected and further stages of design are undertaken, the station analysis will have provided the basic information needed to further highlight the positive impacts on the station site. The knowledge of land use and of the availability of commercial and other services in the neighborhood might indicate activities that could be included within the station site to benefit the community and improve station utilization. A properly designed station could lead to the upgrading of the whole neighborhood.

SUMMARY AND CONCLUSIONS

The methodology presented in this paper complements the standard UTPS. The procedure is relatively straightforward, and yields highly reliable data that are critical to developing circulation and station design criteria. In addition, the procedure optimizes the relationship between walk, bus, and automobile access modes to a particular station within a well-defined geographical area. It further allows interfacing of both manual and computer techniques to provide a total picture of projected use of planned subway stations. The procedure reduces the degree of abstraction so that the results are more meaningful and understandable to planners, decision makers, and the public, who generally have a reasonably accurate, comprehensive, and intimate knowledge of their community. Thus, the planning process is improved, and a better facility is likely to be built.

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Development and Application of Time-Series Transit Ridership Models for Portland, Oregon

MICHAEL KYTE, JAMES STONER, and JONATHAN CRYER

ABSTRACT

Described in this paper are the development and application of a methodology to identify and analyze the factors that influence changes in public transit ridership. The data used in the model development and testing are from Portland, Oregon and cover the period 1971 through 1982. Models were developed at the system, sector, and route levels, and were used to assess the impacts of past changes in service level and fare, as well as to forecast future transit patronage. The statistical approach used here was developed by Box and Jenkins for time-series data, and is therefore more appropriate and powerful than the more traditional regression analysis. Of particular interest here is the identification of the lag structures and functional forms that constitute the relationships between transit ridership, level of service, travel costs, and market size.

Analysis of past variation in transit ridership and forecasting of future ridership are two important concerns for the public transit analyst. Before a service or fare change is instituted, its potential impact on ridership must be assessed. After implementation and equilibrium conditions have been reached, the impact of the change must be analyzed. Has ridership increased or decreased, and has this been the result of the service or fare change? Often it is difficult to isolate the variation in ridership that can be attributed to a fare or service level change from the effects of some exogenous factor such as a change in gasoline supply or price.

There are usually several processes that are occurring simultaneously, each affecting ridership in some way. A change in transit ridership in 1979, for example, might have been strongly related to rapidly increasing gasoline prices and supply constraints. But changes in the size of the travel market or in the level of transit service would also have had a direct impact on ridership levels if these variables were also changing during this time. Thus, any study of the variation in transit ridership must consider all of the relevant factors that are also exhibiting variation. Similarly, to satisfactorily forecast future transit ridership, a clear understanding of these factors is necessary.

Two basic classes of models (cross-sectional and time-series) have been developed by transportation analysts. Each class seeks to define the nature of travel demand and the factors that influence it. Cross-sectional models are developed using data collected at one point in time. Often, intensive travel surveys are undertaken and detailed characteristics of the transportation system are measured. The level of detail of the data allows the development of models that are able to relate microlevel characteristics of the system. For example, characteristics of individual trip-making patterns such as traveler demographics and travel costs and time by competing modes can easily be handled with cross-sectional models. However, using these models to assist in evaluating the impacts of a change over time involves some degree of risk. It is not clear that structural relationships estimated at one point will remain stable over time. In addition, data are expensive and time-consuming to collect and analyze. Time-series models are based on data collected over a period of time and thus allow for direct measurement of the nature of these dynamics. The trade-off is that the level of detail for time-series data is usually not nearly as great as for cross-sectional data. This reduces the precision with which time-series models can approximate true time-dependent structural relationships in the data. However, time-series data are typically collected regularly by the transit operator and are readily available to the analyst. Because the nature of these relationships may itself change over time, it seems clear that models based on time-series data are more likely to capture these dynamics than those based on cross-sectional data.

There have been several important efforts in recent years in the development of time-series-based transit ridership models. Of particular importance is the work of Gaudry (1,2), Kemp (3,4), and Wang (5,6). The data in this paper are built on the work of these researchers, and extend it into several important areas:

1. A methodology is proposed that provides a logical framework for the analysis and forecasting of transit ridership. The essence of the methodology is that in order to assess past impacts or to forecast future variation, a model must be developed that is time-series in nature and explicitly considers all of the relevant factors that influence transit ridership.
2. Consideration is given to the functional relationship between the input variables and transit ridership, particularly the nature of the delay that exists between a change in an input variable and when its effects in ridership can be measured. Also of importance is the method of specifying transit service level when using time-series data.
3. Extensive use is made of a statistical methodology that has not had wide application in transportation, the Box-Jenkins time-series models. This technique resolves several problems that occur when standard regression models are used with time-series data, including multicollinearity and serial correlation. Recent availability of the appropriate com-

puter software makes use of this approach practical and available to most analysts.

METHODOLOGY

The proposed methodology that has been used in this research includes three phases. The first phase, model development, consists of postulating the form of the model, identifying the structural relationships between transit ridership and the input variables, estimating the model parameters, and checking the validity of the model. Impact Analysis is the second phase. Here, the model that has been developed is used to determine the impact on ridership of a previous change in transit service level or fare. The final phase is forecasting, in which the model is used to forecast future transit ridership levels (Figure 1).

Model Development

It is hypothesized that transit demand can be described as a function of level of service, cost, and market size. This approach has been variously used by Gaudry (1,2), Kemp (3,4), and Wang (5,6).

A model structure suggested by theory must be tempered with the reality of the data that is actually available. The model considered here has been developed with this balance in mind. the model can be written as

$$R_t = F(SL_t, TC_t, MS_t, S_t, I_t) + N_t \quad (1)$$

where

R_t = transit ridership,
SL_t = level of transit service,
TC_t = travel costs by automobile and by transit,
MS_t = size of the travel market,
S_t = seasonal factors such as weather,
I_t = interventions such as gasoline shortages, marketing plans, and so forth, and
N_t = the noise model or error structure.

The first issue to be considered with respect to model form is the level of change that can be expected for a given change in the input. In other words, does that relative change in transit ridership depend on whether the change in the input is large or small? It is assumed here that changes in transit ridership resulting from changes in service level or travel costs are subject to the law of diminishing returns. That is, for a fixed market size, there is a maximum number of transit riders that can be expected to use the transit system (assuming no capacity constraint) even if service level is raised to an extremely high level and if the transit fare is zero. For a variety of reasons, some travelers must or will always use their automobile no matter how attractive public transit becomes. Thus, for each additional increment of service level that is added, for example, there will be a smaller increase in the number of new riders that result. While a more generalized functional form can be used, log transformations, which have other useful properties as well, have been used here.

The second issue with respect to model form is that of lagged response. Changes in service level, travel costs, or market size do not always result in instantaneous changes in transit ridership. It takes time for potential riders or current riders to hear about or perceive a change in the level of service, for example, and then make decisions about whether to change their pattern of usage. For this reason, the function relating transit ridership to changes in the independent variables must allow for these lag effects. While the form of the lag is unknown, it may have the form as shown in Figure 2.

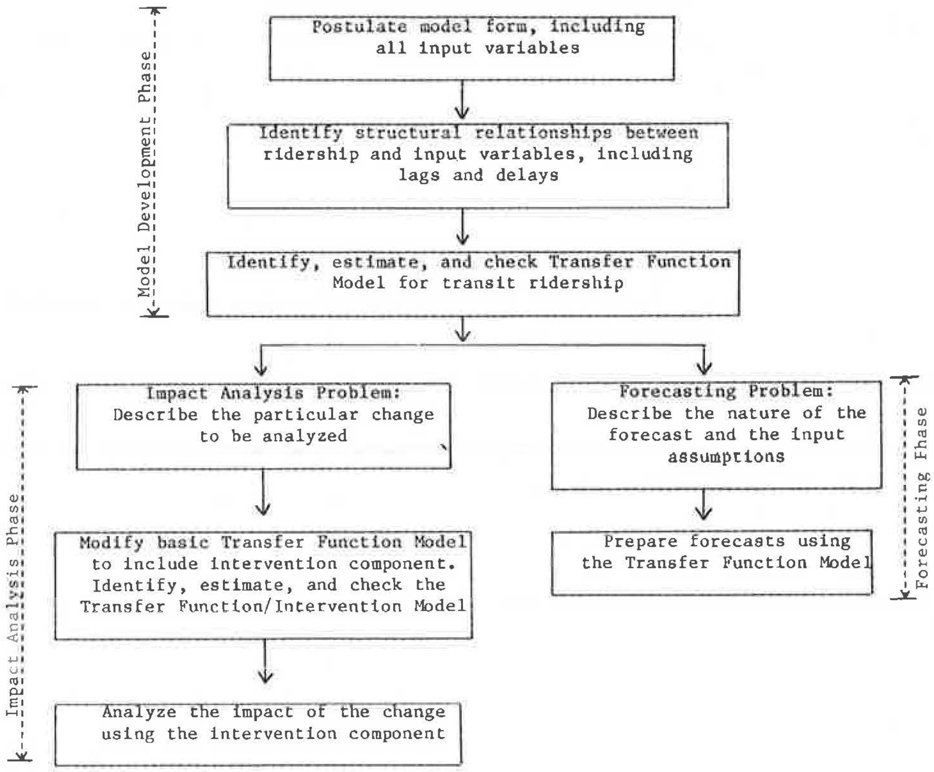
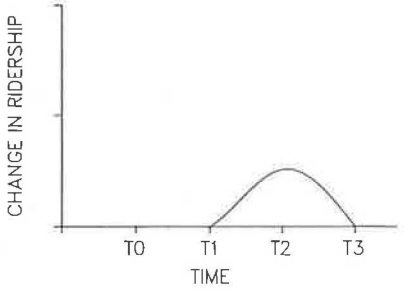


FIGURE 1 Methodology for analysis and forecasting of public transit ridership.



T0 = Time at which change in service level or fare is implemented
T1 = First response in ridership to the change is measured
T2 = Maximum response
T3 = Time at which response/effect disappears

FIGURE 2 Lagged response.

Previously, the variables of the model were listed in general form as service level, travel cost, market size, and seasonal variation. The final issue with respect to model form is the specific form of the variables.

Service Level

One of the major determinants of transit ridership is the level of service available on the transit system. Most cross-sectional travel demand models use such measures as in-vehicle time, waiting time, and access time by transit and by automobile for each origin-destination pair to describe level of service. In time series models, however, the data is simply not available at this level of disaggregation. Typically, time-series demand models use such measures as platform hours or miles of service as a surrogate for transit service level. [Exceptions are Gaudry (1) and Kemp (3,4), who each attempted to construct waiting time and in-vehicle time time-series for Montreal and San Diego. Gaudry was working at the system level, while Kemp was working at the route level.] Here, platform hours, platform miles, and route miles are used.

Platform hours and platform miles are gross measures of the amount of service provided each day, but each also includes nonservice layover and deadhead time. Route miles describes the extent of the coverage of the system. Classification of the data by service change category (frequency of service, times of operation, network modification, new route, service reduction, and route elimination) provides a further useful refinement. Combinations of these three variables are also of interest. Platform miles per platform hour yields a crude measure of system speed, while platform miles per route mile describes the intensity of service over a given network.

For the Portland data, at the route and sector levels, these variables are reasonable estimates for level of service. At the system level, the aggregation of service level into one variable such as platform hours results in a variable that is insensitive to the variation of ridership productivity by geographic sector of the service area. For this reason, the service level variable has been disaggregated by sector, even when using the system data.

Travel Cost

Two variables are used to describe travel cost: transit fare and gasoline price. Transit fare is the actual (average) cost for a transit trip, while gasoline price is a surrogate for the cost of an automobile trip. Assuming that trip lengths have remained fairly stable between 1973 and 1982, gasoline price is a reasonable estimate of automobile travel costs. It can be argued on economic grounds that both transit fare and gasoline price should be deflated using the consumer price index [see Kemp (3,4) for a discussion of this approach]. However, it was found here that nondeflated prices are more directly correlated with transit ridership. The size of the travel market (market size) is described by employment.

Seasonal Variation

Transit ridership varies in a seasonal manner for two major reasons. First, ridership declines in the summer are directly related to vacations from school and work. Second, adverse weather conditions during the nonsummer months (particularly during the winter) often make transit more attractive than walking or using an automobile. In regression analysis, seasonal variation must be specifically accounted for by dummy variables. Seasonal variation can be considered in the transfer function models more simply by adding a seasonal difference and/or a seasonal multiplicative component to the error structure of the model.

Other Variables

The variables listed previously are the primary ones considered here. Others that could be tested include the effects of gasoline supply constraints (1973-1974 and 1979), marketing and promotional programs, and construction of capital facilities.

Identifying, Estimating, and Checking the Model

The statistical methodology that has been used to develop these models has come to be known as the Box-Jenkins approach. The models themselves are known as autoregressive-integrated moving average (ARIMA) models. This approach is based on the philosophy that models should be parsimonious (or represented with the smallest possible number of parameters) and that model building should be iterative. That is, there is a logical sequence of steps and checks that should be followed when constructing a model and that may need to be repeated until a satisfactory model results. These steps include identification of a tentative model based on various statistics constructed from the data itself, estimation of parameters for the tentatively identified model, and diagnostic checking for model adequacy. One of the most important aspects of this approach is that the form of the model is not assumed in advance but is inferred based directly on the data. While theory may provide some guidance regarding which variables to include and the signs of the model coefficients, the analyst must look to the data for clues regarding the lag structure of the independent variables and the error structure of the model.

Tentative models are identified by analysis of the autocorrelation function (ACF) and partial autocorrelation function (PACF) of a given series z_t. For a discussion of the ACF and PACF, the reader is referred to Box and Jenkins (7). The class of ARIMA models of particular interest here is the transfer function model, which can be written as

$$Y_t = \sum_i [\omega_i(B)/\delta_i(B)]\, X_{it}\, [\theta(B)a_t/\phi(B)] \qquad (2)$$

where Y_t is the dependent variable, or the transit ridership series in this case. The X_{it} terms are the independent variables or those factors that explain or effect the variation in Y_t. The polynomial ratio $\omega_i(B)/\delta_i(B)$ represents the lag structure associated with the variable X_{it}. The error structure is represented by the ARIMA model $\theta(B)a_t/\phi(B)$.

An example may help to illustrate this general form. Suppose that two factors, service level (SL) and transit fare (F) are found to affect transit ridership. Further, the effects of a service level change begin immediately and decay over the next several time periods, while transit fare has an impact one period (month) after a fare change. Then, the general model (Equation 2) can be written as

$$R_t = (\omega_0/1-\delta B)SL_t + \omega_1 F_{t-1} + [\theta(B)a_t/\phi(B)] \qquad (3)$$

Several methodologies exist for identifying the form of the transfer function model. The one used here is not unlike stepwise regression in which one variable is added to the model at a time. The following steps are included in this process:

Step 1. Differentiate between each series of interest so that each is stationary.

Step 2. Analyze the ACF and PACF for the dependent variable (or output series) Y_t. The ARIMA model suggested for this series should then be used as the first approximation for the noise model of the transfer function model so that

$$Y_t = \theta(B)a_t/\phi(B) \qquad (4)$$

Step 3. Add the first variable X_{1t} to the model with a lag structure sufficient to cover all lags possibly suggested by theory. Estimate the parameters of this model using generalized least squares methods so that

$$\begin{aligned} Y_t &= \nu_0 X_{1t} + \nu_1 X_{1t-1} + \nu_2 X_{1t-2} + \cdots \\ &\quad + [\partial(B)\ a_t/P(B)] \\ &= \nu(B)x_{1t} + [\theta(B)a_t/\phi(B)] \end{aligned} \qquad (5)$$

Step 4. Analyze the coefficients $\nu(B)$ representing the lag structure for the variable X_{1t} and keep only those that are statistically significant $[\nu'(B)]$ and of the correct sign. Re-estimate the model parameters using only those coefficients $v'(B)$ so that

$$Y_t = \nu'(B)x_{1t} + [\theta(B)a_t/\phi(B)] \qquad (6)$$

Step 5. Add the second variable X_{2t} and follow the procedure of Steps 3 and 4. After analysis and re-estimation, the model will be of the form

$$Y_t = \nu'(B)x_{1t} + \nu'_2(B)x_{2t} + [\theta(B)a_t/\phi(B)] \qquad (7)$$

Step 6. After all of the input variables have been added in this manner, and the significant ones identified and estimated, the model can be estimated in its more parsimonious form of

$$Y_t = \sum_i [\omega_i(B)/\delta_i(B)]\ X_{it} + [\theta(B)a_t/\phi(B)] \qquad (8)$$

where

Y_t = the output series,
$\omega_i(B)/\delta_i$ = the transfer function polynomial ratio,
X_{it} = the input series,
$\theta(B)/\phi(B)a_t$ = the ARIMA noise model, and
B = the backshift operator.

Step 7. Finally, the independence of the residuals a_t, the adequacy of the noise model $[\theta(B)a_t/\phi(B)]$ and the independence of the a_t series with each X_{it} series can be checked.

If all conditions are satisfied, the model is assumed to be in its final form. It should also be noted that a one-way relationship is assumed between X_{it} and Y_t; that is, X_{it} may cause changes in Y_t, but not vice versa. Although this assumption is a reasonable approximation for this case, it should be pointed out that, in fact, a two-way relationship does exist. For example, continued growth in transit ridership will eventually require an increase in capacity and thus in level of transit service provided. This case can be handled by the general multiple time-series model, but will not be covered in this report. For a discussion of the multiple time-series methodology, see Tiao and Box (8).

Impact Analysis

The transfer function model developed in the first phase (model development) provides an indication of the average response of transit ridership to changes in service level or transit fare. The model is estimated based on all of the service level or transit fare changes that occur during the period for which the data are available and thus the elasticities represented by the model coefficients represent the combined effect of all of these changes. If, however, the analyst desires to study the impact of one particular change, that change must somehow be isolated from the other changes that occurred during the study period. This can be achieved using intervention analysis.

Intervention analysis, developed by Box and Tiao (9), is based on the transfer function model but with the addition of a variable that represents one specific change or event. The event, which could be a strike, the implementation of a marketing program, or a gasoline shortage, is represented by a binary variable ζ_{jt}, which assumes a value of 0 before or after the event and a value of 1 during the time that the event or intervention is taking place.

The basic form of the transfer function model with intervention is

$$\begin{aligned} Y_t &= \sum_i [w_i(B)/\delta_i(B)]\ X_{it} + \sum_j [w_j(B)/\delta_j(B)]\ \zeta_{jt} \\ &\quad + [\theta(B)/\phi(B)]a_t \end{aligned} \qquad (9)$$

The variables of Equation 9 are the same as previously defined for Equation 8, with the addition of the j intervention variables ζ_{jt}.

The following steps are included in the impact analysis:

Step 1. Identify, estimate, and check the transfer function model. This represents the model development phase.

Step 2. Describe the past change whose impact is to be analyzed. Formulate an intervention variable to represent this change.

Step 3. Modify the data base to eliminate the effects of this change from the other data representing this variable. For example, if the impact of a previous \$0.05-fare increase is to be analyzed, this increase should be subtracted out of the fare data.

Step 4. Re-estimate the model with the intervention variable included, as in Equation 9. If the coefficient of the intervention variable is statistically significant, the coefficient represents the effect of the specific change under analysis. If the coefficient is not statistically significant (that is, not significantly different than zero), then the intervention had no measurable impact on transit ridership.

Forecasting

The transfer function model developed in the first phase (model development) can also be used to forecast future levels of transit ridership. But because the model depends on several inputs, these variables must also be assumed or forecast. Some of the input variables are under the direct control of the transit manager (e.g., service level and fare), and thus, a given policy option (e.g., reduced fares) can be assumed. Other variables such as employment and gasoline price, however, are exogenous and these must be forecast directly. Forecasts of the input variables are accomplished by using "univariate" models. A univariate model for gasoline price is simply a model of today's gasoline price as a function of past values of gasoline price.

The following steps are included in the forecasting phase:

Step 1. Identify, estimate, and check the transfer function model. This represents the model development phase.

Step 2. Describe the nature of the forecast problem including the input assumptions and the length of the forecast period.

Step 3. Forecast the future values of the exogenous input variables, such as employment and gasoline price.

Step 4. Using either the forecast or assumed values for the input variables, forecast the future values of transit ridership.

The actual computations involved in transfer function forecasting are complex and are not described here. Several computer programs include the forecasting process and, once a transfer function model has been developed, are straightforward and easy to use. See, for example, SAS (10) and SCA (11) for further information.

CASE STUDY: PORTLAND, OREGON

The Portland, Oregon metropolitan area includes 1.2 million people and covers over 900 mi². The transit operator in Portland is the Tri-County Metropolitan Transportation District of Oregon (Tri-Met). Tri-Met was formed in 1969 by the Oregon legislature to take over the private bus operations within the City of Portland and to expand services into the rapidly growing three-county area.

Starting from 50,000 weekday riders in 1970, ridership had grown to over 140,000 by 1980, averaging a 9-percent annual growth rate. The 3-year period 1973-1976 saw nearly a 20-percent annual increase. Platform hours and miles increased at an annual rate of nearly 7 percent between 1972 and 1982. The major period of expansion was from 1973 to 1976 when the annual growth rate was 14.5 percent. Area coverage, as measured by route miles, increased by 4.3 percent annually during this 10-year period. Service level intensity (platform miles per route mile) increased by an annual rate of 11.5 percent from 1973 to 1976, but remained constant between 1976 and 1982.

By nearly all measures, automobile travel costs increased significantly during this period, while transit travel costs declined. Gasoline price increased at a 15.6-percent annual rate during the 10-year period, with the largest increase occurring between June 1979 and June 1980, when a 30-percent annual rate was recorded. Employment increased at an annual rate of between 2 and 5 percent until 1980 when it began to decline. Some of these trends are shown in Figures 3 through 7.

Model Development Phase

Data for Portland, Oregon covering 1971 through 1982 were used to develop a total of 16 transit ridership models: one for the system as a whole, six representing distinct geographic sectors of the Portland region, and nine for individual routes in the Portland transit system. The three different data sets used here and their interrelationships are given in Table 1.

Four input variables were used for each of the models: transit service level, transit fare, gasoline price as a surrogate for automobile operating costs, and employment as a measure of the travel market size. Natural logarithms of the data were used, so that model coefficients give the elasticities directly for each variable. The nature of the market response was included in the model by introducing lagged variables. This allowed a direct assessment of the time delay between the introduction of a service level or fare change and when a change in ridership could be measured. Service level delays ranged from 1 to 10 months for the system model and 0 to 3 quarters for the sector and route models. Fare delays ranged up to 2 quarters. A summary of the elasticities and lags are given in Table 2.

Examination of Table 2 shows that there are some important consistencies in the results obtained by the three model categories. For example, the response delay to service level changes tends to be about two to three times longer for urban routes than for suburban routes. Another comparison is the consistency of the elasticities for the four input variables between the system model and the sector models, as shown in Figures 8 and 9. Note that the elasticities estimated for the six sector models tend to vary around the system mean for each variable.

Impact Analysis Phase

The elasticities computed in the model development phase represent an average elasticity for a given variable over the entire study period. If four service changes were implemented during a given period, for example, the service level elasticity would be an average of the impact of each service level change. However, to study the impact of a specific service level change, an intervention variable, which represents that change alone, must be added to the model. The model is then re-estimated with the intervention variable and the coefficient yields the elasticity of the specific change under study. If the variable coefficient is not statistically significant, it can be concluded that the change had no measurable impact on ridership.

Eleven service changes instituted between 1973 and 1979 were analyzed using the intervention analysis technique. The results are given in Table 3. Seven of the eleven changes were found to have had a significant impact on ridership.

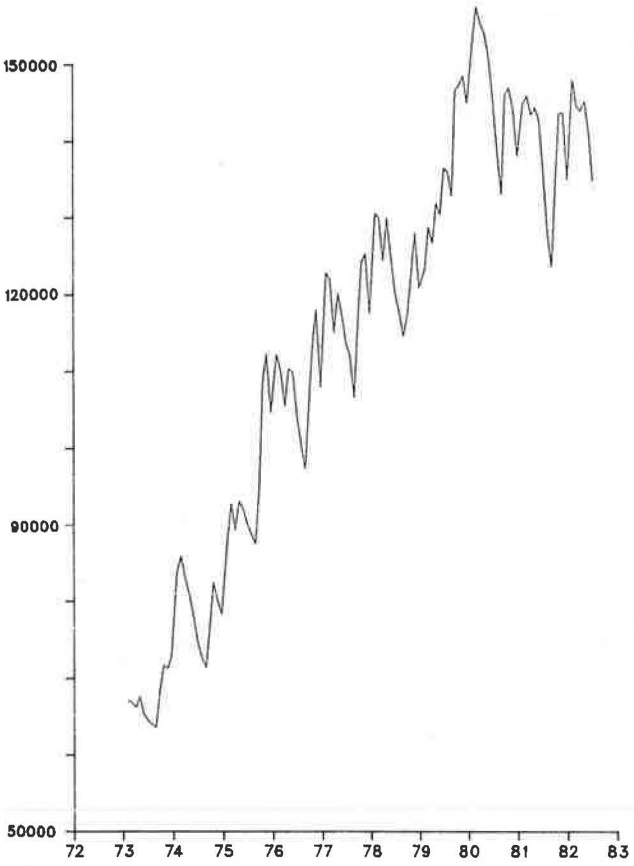


FIGURE 3 Transit ridership, system level, Portland data.

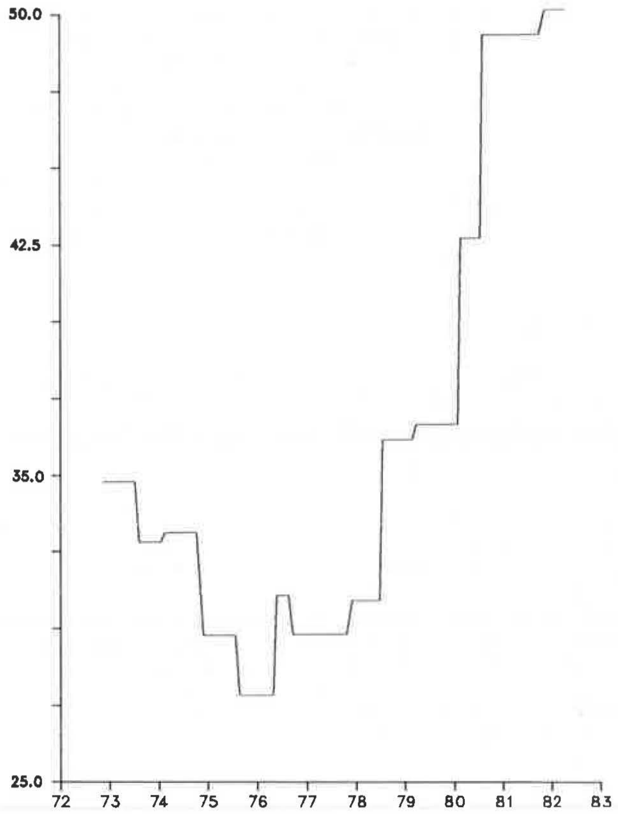


FIGURE 5 Average transit fare, Portland data.

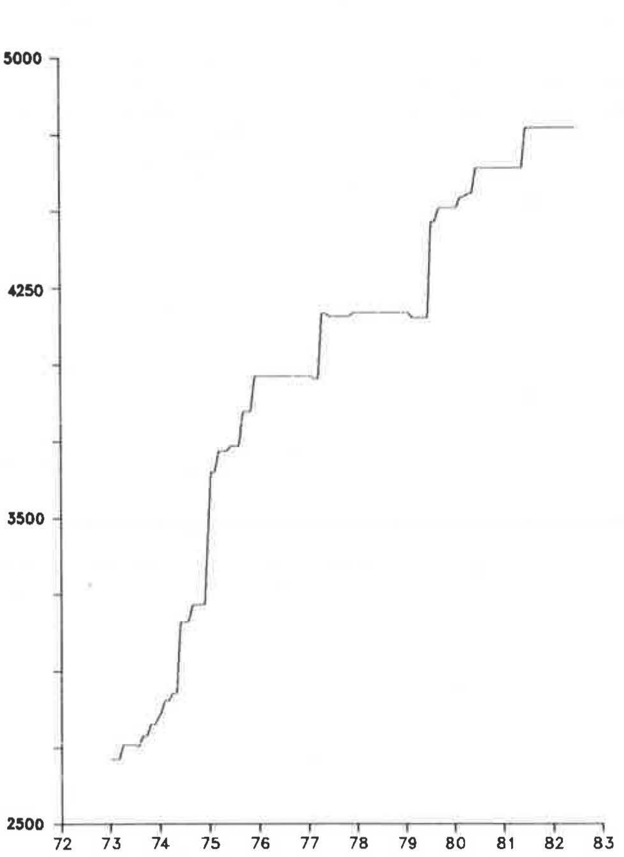


FIGURE 4 Platform hours, system level, Portland data.

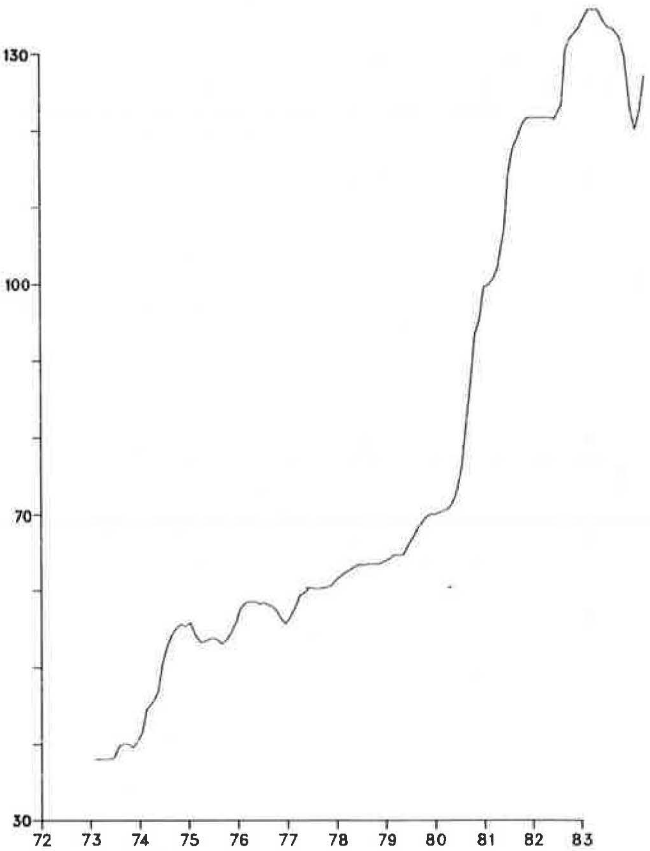


FIGURE 6 Gasoline price, Portland data.

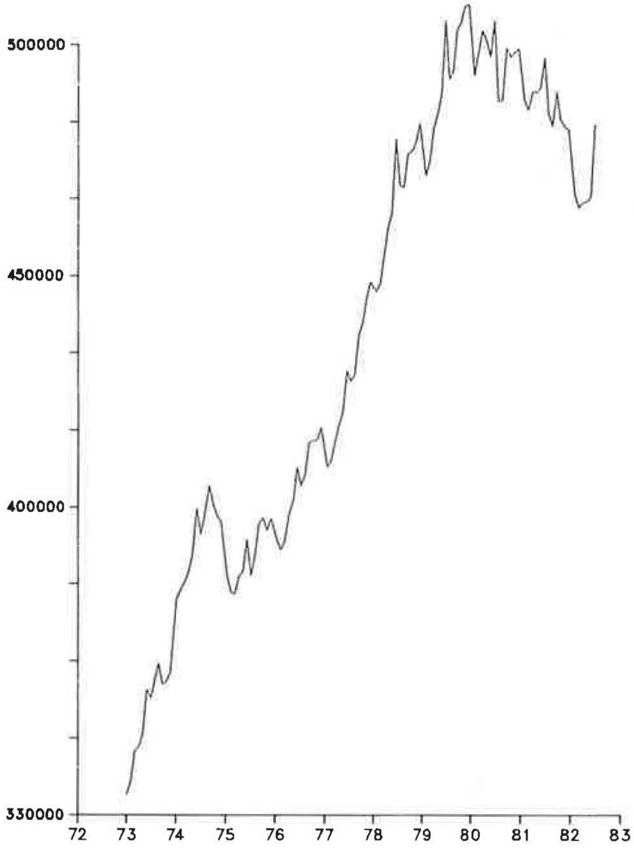


FIGURE 7 Tri-County employment, Portland data.

Forecasting Phase

The models developed in the initial phase of this project can be used to forecast future transit ridership variation. For example, the impact of a future fare change can be estimated using the appropriate model. But because the model depends on future variation in gasoline price and employment as well, these variables must also be forecast or assumptions must be made about their future values.

Figure 10 shows the results of a forecast of system ridership for 12 periods (months) ahead. It was assumed that service level and fare were set by policy and that gas price and employment had to be forecast using time-series models. These results, with a mean absolute percent error of 2.1 percent, show the high quality of forecast that can be achieved by using this approach.

TABLE 1 Summary of Portland Data Base

Variable	Time-Series
System level data	
Transit ridership	Average weekday originating transit riders
Service level	Daily platform bus hours Daily platform bus miles Daily route miles Daily platform miles per route mile
Travel costs	Average bus fare in cents Gasoline price per gallon in cents
Market size	Total employment by county
Sector and route level data	
Transit ridership	Total weekday boarding riders
Service level	Daily platform bus hours Daily platform bus miles Daily route miles Daily platform miles per route mile
Travel costs	Average bus fare in cents Base cash fare in cents Gasoline price per gallon in cents
Market size	Total employment by county

COMPARISON WITH STANDARD REGRESSION MODELS

It has been traditional to use multiple regression models when developing models that relate transit ridership to explanatory variables. Using time-series data with regression models, however, invariably leads to a variety of statistical problems. Table 4 contains data that highlight the following major areas in which problems are likely to arise by contrasting standard regression with transfer function models: multicollinearity, autocorrelated errors, lag structures, and coefficient estimates and standard errors. To determine whether these problems would, in fact, result, both standard regression and transfer function models were developed using the Portland system data.

In using the nondifferenced data, a high degree of correlation was found among the input variables. Seven of the ten input variable combinations were highly correlated, with correlation coefficients of

TABLE 2 Summary of Models

	Model Description		Service Level		Fare		Gas Price		Employment	
Data Aggregation	Data Period	Model Description	Elasticity	Lag	Elasticity	Lag	Elasticity	Lag	Elasticity	Lag
System	Monthly	System	.51	1,10	-.29	0	.32	0	.49	0
Sector	Quarterly	City radial lines	.71	2	-.13	0	.14	0	.43	0
		City crosstown lines	.60	0-3	-.42	0	.39	0	-	
		Urban Eastside lines	.55	2	-.15	0	.18	0	.65	0
		Westside suburban lines	.80	0	-.32	0	.31	0	.47	0
		SW suburban lines	.49	0	-.22	1	.28	0	.67	0
		SE suburban lines	.88	0,2	-.16	0	.27	0	.69	1
Route	Quarterly	City radial line								
		Route 2	1.81	0,2	-.39	0	.72	0	1.14	2
		Route 3	1.73	0,2,3	-.90	0,1	1.39	0-3	-	
		Route 6	.23	0	-.80	0	.62	0	.95	0
		Route 8	.25	3	-.35	2	1.23	0,1	-	
		City Crosstown line								
		Route 71	.72	0	-		3.24	2	-	
		Route 72	.55	0	-		.68	3	-	
		Route 73	–		-		.60	0	-	
		Route 75	–		-		1.72	3	-	
		Route 77	.35	0	-		.24	2	-	

Note: Elasticity = total elasticity for given variable. Lag = lag or delay for which change in ridership was measured. A lag of 2 using quarterly data, for example, indicates that a change in ridership was measured 2 quarters after the input variable was changed.

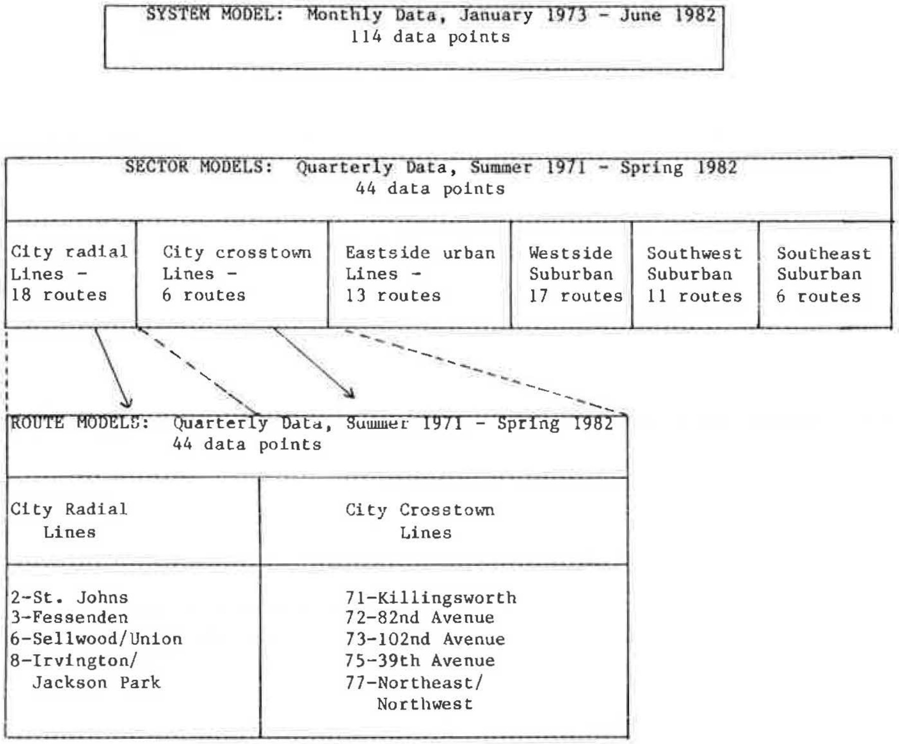


FIGURE 8 **Summary of models developed and their interrelationship.**

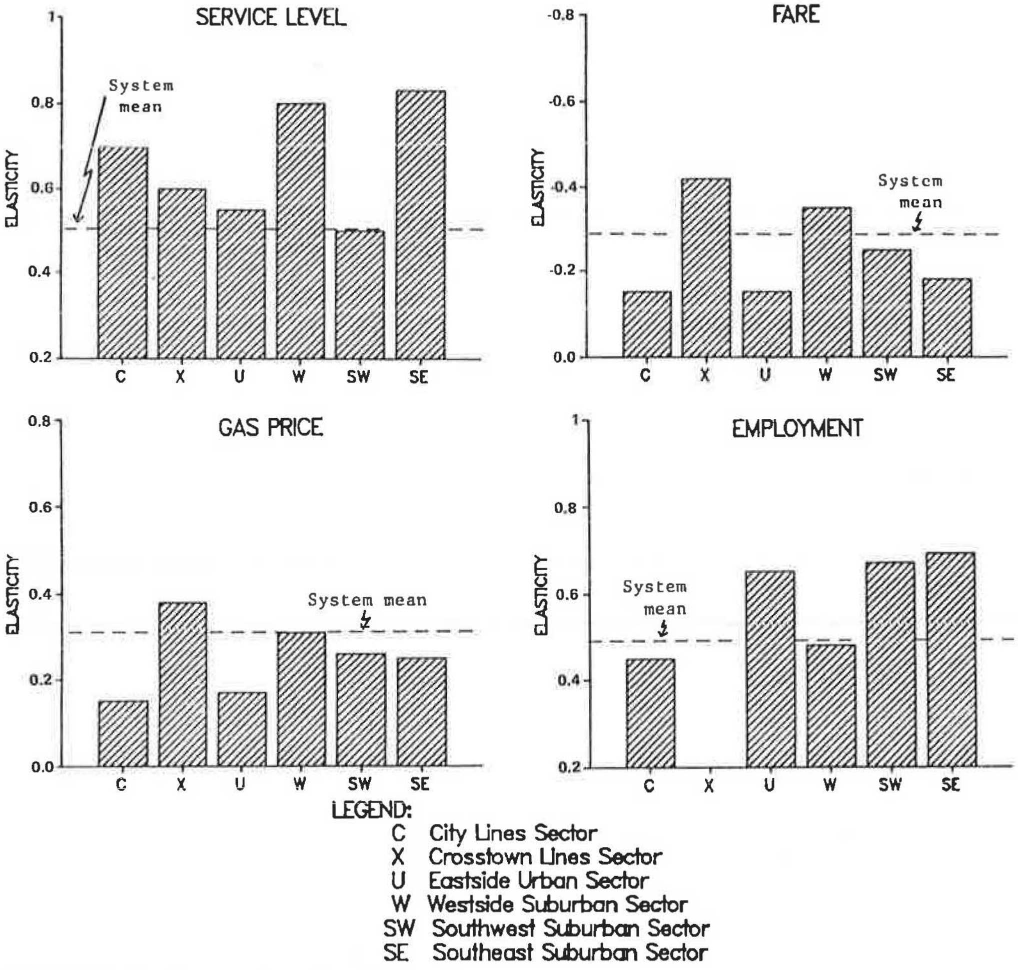


FIGURE 9 **Consistency of model coefficients between system and sector models.**

TABLE 3 Impact Analysis of Past Service Changes at the Route Level

Route	Date	Type of Change	Significant Impact?	Coefficient of the Intervention Variable
2	1975	Frequency improvement	Yes	.13
	1978	Route extension	No impact	–
3	1973	Frequency improvement	Yes	.11
	1974	Frequency improvement, route extension	Yes	.13
	1978	Service reduction	No impact	–
6	1974	Route extension	No impact	–
	1975	Frequency improvement	Yes	.23
71	1979	Frequency improvement, route extension	Yes	.72
72	1976	Route extension	Yes	.81
75	1979	Route extension	No impact	–
77	1979	Frequency improvement	Yes	.35

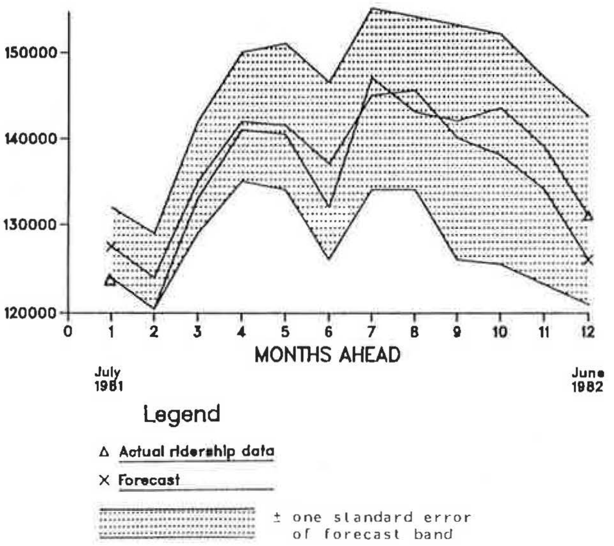


FIGURE 10 Comparison of forecasts, system model.

0.60 or greater (see Table 5). Second, the residuals were highly correlated and not independent as required for regression models. Third, the delay in the response to service level changes would have been missed if only contemporaneous correlations were included in the model. Finally, the biased standard errors from the regression model would have erroneously led to the conclusion that one of the variables (service level-suburban lines) was statistically significant when in reality it was not (see Table 6). These results argue for the wider application of the appropriate statistical methodology when time-series data are used.

CONCLUSIONS

This paper has presented the initial results from the development and application of Box-Jenkins transfer function and intervention models to time-series transit ridership and operations data for Portland, Oregon. The results indicate that this methodology is appropriate for evaluation and forecasting of transit ridership changes. Evidence is presented for the lag structure of the market response to the various factors that influence transit ridership. Service level changes, for example, may require up to 2 quarters or 10 months for their effects to be realized, while fare changes have lag effects of up to 1 quarter or 1 month. Response to gasoline prices and employment level changes are more rapid, though lag effects have been found at the route level for up to 3 quarters for gasoline price changes.

This work has also shown the consistency of results that may be obtained between system and route models when using different data bases. In addition, the effectiveness of intervention variables to model a specific change or event was demonstrated. Finally, some evidence was found on the variation of the structural relationships in the model over time.

While requiring a somewhat longer learning period than would more traditional multiple regression analysis, time-series ARIMA models offer a substantial advantage to the transportation analyst. With the recent availability of new computer software designed specifically to handle time-series problems, their use in transportation analysis will hopefully increase.

There are several areas in which further research is needed; some of this work is now underway by the authors of this paper, including:

1. Development of route level models for all 37 route pairs operated by the Portland transit system. This will enable a thorough statistical analysis of elasticity measures of service level and transit fare, and a better categorization of impact of these changes.
2. Development of multiple time-series models that will enable a study of two-way causality. Multiple time-series models are much more difficult to develop than transfer function and intervention models, but the results of the work provide more

TABLE 4 Comparison of Standard Regression and Transfer Function Models

Comparison	Standard Regression	Transfer Function
Correlated input variables	Yes, the input variables are highly correlated; multicollinearity is present	No, data are differenced
Automobile-correlated errors	Yes, the error structure is highly autocorrelated, violating basic model assumptions	Yes, but model structure allows for correlated errors
Lag structure for input variables	No, only contemporaneous correlation assumed	Yes, methodology directly investigates the nature of dynamic relationships
Coefficient estimates and standard errors	Estimates are inefficient and the standard errors (and thus the significance tests) are biased	Estimates are efficient and the standard errors are unbiased

TABLE 5 Correlation Matrix Showing Multicollinearity of Nondifferenced Data

	Service Level				
Input Variables	City Lines	Suburban Lines	Fare	Gasoline Price	Employment
Service level					
City lines	1.00	.96	.45	.85	.89
Suburban lines	.96	1.00	.48	.88	.84
Fare	.45	.48	1.00	.80	.60
Gasoline price	.85	.88	.80	1.00	.89
Employment	.89	.84	.60	.89	1.00

TABLE 6 Comparison of Coefficient Estimates: Standard Regression versus Transfer Function Models

	Coefficient Estimate and Standard Error	
Input Variables	Regression	Transfer Function
Service level		
City lines	.39 ± .21	.28 ± .17
Suburban lines	.31 ± .12	.08 ± .06
Fare	-.30 ± .08	-.28 ± .07
Gas price	.27 ± .07	.25 ± .11
Employment	.48 ± .09	.57 ± .26

useful insights into the structure and dynamics of the factors that influence change in transit ridership.

ACKNOWLEDGMENTS

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Forecasting Future Transit Route Ridership

HERBERT S. LEVINSON

ABSTRACT

This paper contains an analysis of the ridership potentials of various public transportation options for the Michigan Avenue Corridor in East Lansing (1). Ridership projections were based on: corridor population and employment growth; changes in service levels resulting from the various options; and effects of changes in gasoline price, parking costs, and increased traffic congestion. An origin-destination matrix of bus riders was derived from on-and-off counts. Differential growth rates for various sections of the corridor were developed and applied to this derived matrix to derive future bus trip interchange patterns. Elasticity factors were applied to specific trip linkages to estimate the impacts of reduced travel times for both the $0.35 fare in effect during 1979-1980, and the $0.50 fare placed in effect during June, 1981. Sensitivity analyses were conducted to quantify the impacts of changes in gasoline costs and availability, increased traffic congestion, and changes in downtown parking policy. Ridership estimates were developed for 1985 and 2000 for five service options. The daily ridership would increase from 6,235 passengers in 1980 (with a $0.35 fare) to between 7,200 and 9,000 passengers by year 2000 for a $0.50 fare. Peak-hour one-way riders at the maximum load point would rise from 440 passengers in 1980 to 860 passengers by year 2000 depending on the service option. The ridership forecasting methods have applicability in other urban areas as well. They are particularly valuable where it is reasonable to assume that transit will retain its share of the corridor travel market (i.e., short-range forecasts). Where this is not the case, adjustments can be made to the future-year base service option before elasticity factors are applied.

Many public transportation planning decisions must be based on a limited amount of data. This is especially true for forecasting future route ridership in a small or medium-size community where detailed travel patterns or network information is not available.

Long-term patronage forecasts for corridor transit alternatives in a medium-size urban area--Lansing, Michigan are developed in this paper. It shows how future corridor ridership can be estimated based on on-and-off counts, population and employment forecasts, travel time studies, and elasticity factors.

In addition, the paper also contains an analysis of ridership potentials of various public transportation options for the Michigan Avenue corridor in Lansing and East Lansing, Michigan. It is based on surveys and analyses conducted during 1981-1982 as part of an alternatives analysis study.

GENERAL PROCEDURES

The transit ridership estimates were based on the following steps:

1. A field reconnaissance study was made to identify corridor characteristics, observe traffic conditions, and determine travel times.
2. Available information on population, employment, bus ridership, and traffic flow was assembled and reviewed; this included population forecasts, on-and-off bus ridership surveys; and traffic volume trends. The data were analyzed to obtain a picture of existing conditions and likely changes over the next several decades. Agency projections were modified where appropriate to reflect the 1980 U.S. Census results, and prospects for growth in Michigan State University (MSU) enrollment and Lansing central business district (CBD) employment.
3. A generalized origin-destination pattern for Route 1 bus riders was derived from the Capital Area Transit Authority's (CATA) on-and-off passenger counts.
4. Bus travel patterns for 1985 and the year 2000 were derived, taking into account corridor population and employment growth. Differential growth rates for various sections of the corridor were developed and applied to the derived origin-destination matrix to develop 1985 and 2000 bus trip patterns, assuming that existing bus service is adjusted to reflect and realize this corridor growth.
5. Travel time estimates were developed for five basic transit service options:

- the base condition
- improved bus service
- trolley bus
- high-capital bus (busway)
- light rail transit

6. Elasticity factors were then applied, taking into account (a) changes in service levels resulting from the various options, and (b) effects of changes in gasoline prices, parking costs, traffic congestion, and transit fares as follows:

- The elasticity factors were applied to specific trip linkages to estimate the impacts of reduced travel times for each service option. Estimates assumed that the fares would be the same for each option, and that there would be no sustained fuel shortages or major policy disincentives to driving.
- Ridership estimates were keyed to the $0.35 fare in effect during 1979-1980; they were then

adjusted to reflect the $0.50 fare in effect in June 1981, based on information received from CATA.

- Sensitivity analyses were conducted to quantify the effects of changes in gasoline cost and availability, increased traffic congestion, and changes in downtown parking policy.
- Estimates were prepared for 1985 and 2000 ridership on a daily basis, and also for peak-hour, peak-direction passenger flows past the maximum load point.

The ridership forecasts assumed that the base condition would adjust existing services sufficiently to enable ridership to increase proportional to population and employment growth in the corridor; otherwise, bus ridership would essentially remain at existing levels. Ridership would also increase as service levels in the corridor were improved--the increases would reflect both trips diverted from cars and new trips.

EXISTING CORRIDOR CHARACTERISTICS

The Michigan Avenue Corridor was defined as an area approximately 1 mi wide bisected by Michigan and Grand River Avenues, having as its western terminus the Lansing CBD, and extending eastward through the East Lansing CBD to Hagadorn Road and beyond to the Meridian Mall--a major generator (see Figure 1).

Development Patterns

The 7-mi corridor had a population of approximately 90,000 people in 1980--approximately 22 percent of the 417,000 people residing in the Tri-County Region. It contained more than 40 percent of the 140,000 jobs in the Tri-County area, including the Lansing CBD (20,500 jobs); MSU (8,800 jobs), and the East Lansing CBD (1,800 jobs). It includes MSU with 45,700 students, the Frandor Shopping center with 500,000 ft^2 of floor space, and Meridian Mall with 1 million ft^2.

Traffic and Person Flows

Daily and peak-hour traffic flows on Grand River Avenue between Michigan Avenue and Bogue Street, as observed by the Michigan Department of Transportation, approximated 39,000 vehicles; peak-hour peak-direction flows ranged from 1,700 to 2,100 vehicles--approximately 4-5 percent of the daily two-way total. The 2,100 vehicles operated in three lanes on a 28-ft wide roadway through signalized intersections in East Lansing. Buses carried approximately 12 percent of the daily person-movements along Michigan Avenue and about 4-8 percent within the corridor. During the morning peak-hour, 11,000 people entered downtown Lansing, of which 11 percent came by bus.

Travel Times and Traffic Conditions

Relatively little congestion was observed in the corridor and its environs. Speeds along Michigan Avenue between Cedar Street and Marsh Road approximated 28 to 32 mph during the a.m. peak, 29 mph midday and 25 to 26 mph during the p.m. peak. They were largely governed by the traffic signal progression that is reportedly set for 30 mph. Travel times between the Lansing CBD and Abbott in East Lansing approximated 8-10 min by car, 15 min by express bus, and 15-20 min by local bus with variations by time of day. Travel times between the Lansing CBD and Marsh Road (Meridian Mall) approximated 14-17 min by car, 25 min by express bus and 30-35 min by local bus (see Table 1).

Bus Ridership

Public transport was provided by two agencies--CATA and the MSU bus system. CATA's bus fleet included 74 buses and 6 paratransit vehicles of which 52 ran in peak periods and 35 ran midday. Weekday CATA ridership averaged 16,000 in 1980, reaching 20,000 on days when MSU was in session. MSU bus system daily ridership ranged from 7,500 in the spring of 1980 to 17,000 during the 1980 winter term. A $0.35 to $0.50

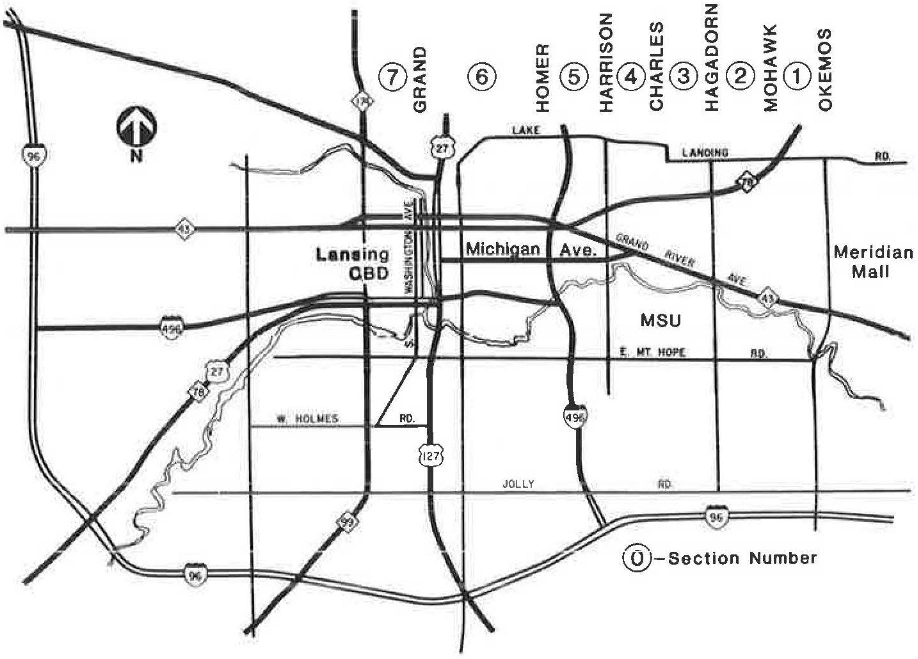

FIGURE 1 Study corridor and environs.

TABLE 1 Michigan Avenue Profile Comparative Avenue Travel Times

Direction of Travel	Grand-Abbott (min) Automobile	Grand-Abbott (min) Local Bus	Grand-Abbott (min) Express Bus	Grand-Marsh Road (min) Automobile	Grand-Marsh Road (min) Local Bus	Grand-Marsh Road (min) Express Bus
Eastbound						
AM	9	15		14	30	
Midday	8	20		15	35	
PM	10	20	15	17	35	25
Westbound						
AM	9	15		16	30	
Midday	8	20		15	35	
PM	10	20	15	17	35	25

Sources: Michigan Department of Transportation speed runs; CATA Route 1 schedules, effective September 15, 1980; H.S. Levinson speed runs, June 1981.

CATA fare increase in 1981 resulted in a 7-8 percent decline in average weekday ridership.

Daily ridership in the corridor totaled 6,235 passengers in 1979, of which Route 1 (East Lansing Mall) carried 5,470 passengers, or one-third of the system's total weekday ridership. Westbound buses during the morning peak hour on a typical April 1980 day had 90 riders on vehicles at the eastern end of the study area (Meridian Mall). The number of riders on buses increased to 280 west of Abbott in downtown East Lansing and reached 440 as buses entered the Lansing CBD.

DEVELOPING TRAVEL PATTERNS

A profile of eastbound and westbound Route 1 ridership was derived from CATA on-off counts. Table 2 gives a summary of weekday eastbound and westbound ridership that includes the following data:

1. The maximum accumulation of passengers that occurred in Section 6 between Homer and Grand.
2. Approximately 47 percent of all riders boarding westbound buses had destinations in the Lansing CBD; similarly, approximately one-half of all eastbound alighting passengers initiated their trip in the Lansing CBD.
3. On the average, 21 percent of all Route 1 riders had their origin or destination in the East Lansing CBD.
4. The surveys also found that approximately 55 percent of the total riders passed the maximum load point--this corresponds to a turnover of about 1.8. One set of (westbound) riders boards buses for destinations at MSU or downtown East Lansing. Another group of riders boards buses west of the East Lansing center for destinations in the Lansing CBD. The bus trips between each pair of sections were derived from the CATA counts on a proportional basis. Because of the short length of most sections, it generally was assumed that bus riders would travel from one section to another. However, in the case of Sections 1 and 6, intra-section trips were included.

Figure 2 shows how the trip matrix was developed. Section 1, for example, had 13 percent of all westbound "on" trips, and 1.1 percent of all westbound "off" trips. Thus, 11.9 percent of these westbound trips were to other sections. Section 2 had 2.1 percent of all westbound "off" trips. Because no intra-Section-2 trips were assumed, these trips came from Section 1. The remaining 9.8 percent of trips from Section 1 were to other sections. Section 3 had 6.8 percent of all "off" trips, which came from Sections 1 and 2. Section 1 contributed 9.8/(9.8 + 13.1) percent or 43 percent, which is 2.9 trips; and Section 2 contributed 13.1/(9.8 + 13.1) percent or 57 percent, which is 3.9 trips. This process was repeated until a complete trip matrix was obtained. It was varied slightly to account for intrazonal trips in Section 6.

The results of this process are given in Table 3. The 1979-1980 Route 1 ridership patterns by type of trip can be summarized as follows (note that Charles is the eastern limit of most transit options):

Type of Trip	1979-1980 Ridership Percent	1979-1980 Ridership Percent (cumulative)
Begin and end east of Charles	10.0	
East of Charles to or from points between Charles and Grand	20.6	
East of Charles to or from Lansing CBD	9.2	39.8
West of Charles to or from points between Charles and Grand	22.4	
West of Charles to or from Lansing CBD	37.8	60.2
	100.0	100.0

TABLE 2 1979-1980 Route 1 Daily Ridership Profile for Both Directions—Percentage Distribution

Section (WB-off; EB-on)	Lansing CBD Orientation (WB-on; EB-off)	Meridian Mall Orientation (EB-on; WB-off)	Accumulation of Riders (% of maximum accumulation on line)
1 Meridian-Mohawk	13.0	1.1	20.2
2 Mohawk-Hagadorn	13.1	2.1	39.5
3 Hagadorn-Charles	13.7	6.8	53.0
4 Charles-Harrison	30.5	12.3	86.9
5 Harrison-Homer	13.3	8.0	96.7
6 Homer-Grand	16.4	22.7	100.0
7 West of Grand	-	47.0	84.4

Note: WB = westbound and EB = eastbound.

Source: CATA ridership survey.

PROJECTING CORRIDOR AND RIDERSHIP GROWTH

General growth trends were derived from an analysis of actual experience and agency forecasts. They were modified as appropriate to reflect results of the 1980 U.S. Census, and likely development in central Lansing. These growth trends were developed before the economic recession occurred in central Michigan; therefore, they may be optimistic when viewed from the perspective of 1985--especially Lansing CBD employment.

Corridor Growth Indices

Growth factor summaries for the corridor are given in Table 4. These indices that 1985 travel would

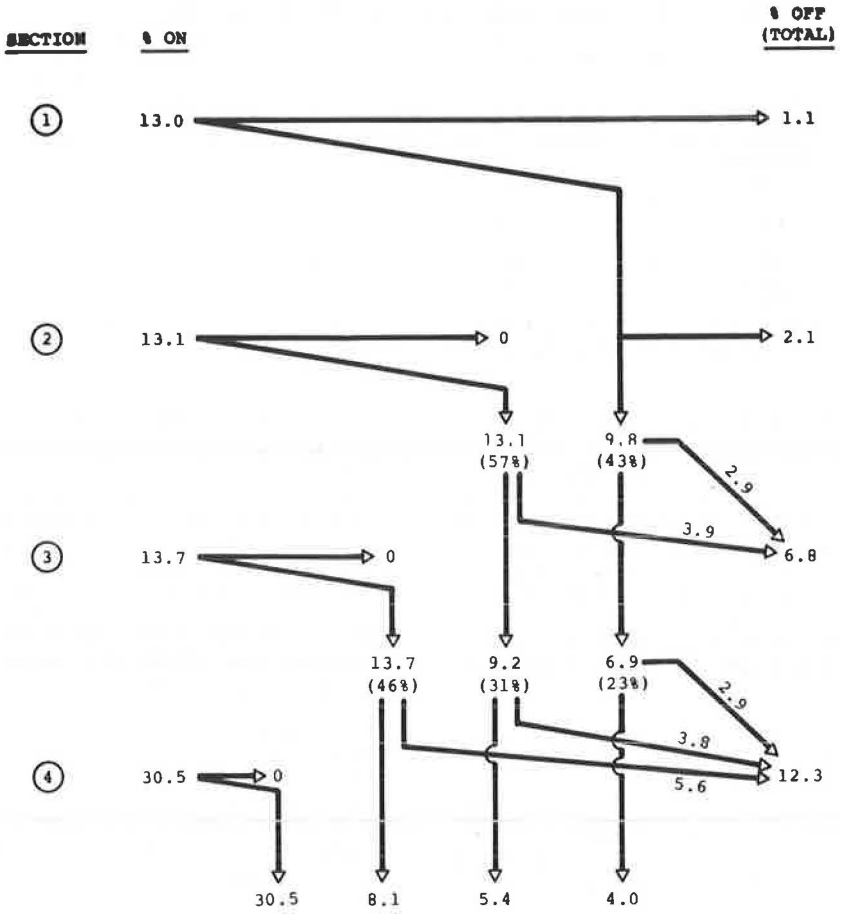

FIGURE 2 Sample development of O-D matrix.

TABLE 3 Estimated Distribution of Route 1 Bus Riders from 1979 to 1980

Section (WB-off; EB-on)	WB-On; EB-Off (%) 1	2	3	4	5	6	7	Totals
1 Meridian-Mohawk	1.1							1.1
2 Mohawk-Hagadorn	2.1	–						2.1
3 Hagadorn-Charles	2.9	3.9	–					6.8
4 Charles-Harrison	2.9	3.8	5.6	–				12.3
5 Harrison-Homer	0.6	0.9	1.4	5.1	–			8.0
6 Homer-Grand	1.2	1.7	2.5	9.4	4.9	3.0		22.7
7 West of Grand	2.2	2.8	4.2	16.0	8.4	13.4	–	47.0
Totals	13.0	13.1	13.7	30.5	13.3	16.4	–	100.0

Note: WB = westbound and EB = eastbound.
Source: CATA ridership survey.

TABLE 4 Travel Growth Indices in the Michigan Avenue Corridor

Basis	Ratios[a] Year 1985	Year 2000
Regional population growth	1.07	1.27
Corridor population growth:	1.08	1.31
East Lansing		
Lansing Township		
Meridian Township		
Corridor employment	1.06	1.21
CBD Lansing employment	1.17	1.36
Traffic growth in East Lansing area	1.05	1.20
Averages	1.09	1.27

[a] Calculated ratios are future year to 1979-1980 base year.

average approximately 9 percent more than in 1980, while 2000 travel would increase approximately 27 percent. Thus, assuming bus ridership in the corridor would retain its present market share, it would grow by 27 percent between 1980 and 2000--from 6,235 to 7,920 riders.

A more refined set of growth factors were derived for specific types of trips in the corridor. Three sets of population factors and four sets of employment factors were developed, drawing on previous analyses and, where needed, the Tri-County zonal employment forecasts. Composite factors for expanding bus trips were then derived based on the geometric mean of employment and population change for specific trip linkages as follows:

Factor (for a trip between Section i and j),

$$F_{2,1} = [(P_2/P_1)_i \times (E_2/E_1)_j]^{1/2} \quad (1)$$

where

Section i = the section furthest to the east, relative to the Lansing CBD;
Section j = the section furthest to the west, relative to the Lansing CBD;
P_1 and P_2 = the population of various zones associated with Section i at times 1 and 2; hence, P_2/P_1 is their ratio; and
E_1 and E_2 = the employment of various zones associated with Section j at times 1 and 2; hence, E_2/E_1 is their ratio.

The various factors that were applied to specific trip linkages are given in Table 5.

Bus Ridership Implications

Bus ridership was estimated for 1985 and 2000 by applying both average and sectional growth factors. In both cases, it was assumed that sufficient service adjustments would be made to enable ridership to keep pace with corridor population and economic growth. It was also assumed that there would be no fare increases, relative to the base year, in real dollars.

Table 6 contains a representation of the anticipated 2000 bus ridership matrix for Route 1. Ridership is expressed on a percentage basis, with 1979-1980 ridership equal to 100 percent. For 2000, Route 1 ridership would increase by 25.7 percent.

Table 7 contains a summary of present and anticipated ridership. Corridor bus ridership would grow from 6,235 in 1980 to about 6,800 in 1985 and 7,900 by 2000. The average and sectional factors give similar results. As in 1980, about 55 percent of the daily riders would pass the maximum load point.

Peak-hour, one-way bus riders at the maximum load point in 1979-1980, 1985, and 2000 are given in Table 8. These calculations assume that the peak-hour riders would increase proportional to daily ridership. Under these assumptions, peak-hour ridership on Routes 1, 13, 15, and the Meridian Mall express would increase from 440 in 1979-1980 to 490 in 1985 and 585 by 2000.

Developing Ridership Projections

Ridership was projected for four basic transit service options based on (a) the effects of changes in travel times and fares, and (b) the effects of changes in other factors.

Initial Assumptions

The initial projections of 1985 and 2000 ridership based on changes in service levels and fares reflected the following assumptions:

1. The base condition would adjust bus service frequencies to reflect ridership generated by population and economic growth in the corridor. Other-

TABLE 5 Growth Factors By Section

Section	Ratios 1985/1980	Ratios 2000/1980
Individual factors		
A. Meridian Township population	1.137	1.549
B. East Lansing population	1.058	1.203
C. Lansing population (in corridor)	1.000	1.000
1. Meridian Township employment	1.080	1.562
2. East Lansing employment (including Frandor)	1.052	1.562
3. Lansing employment (in corridor excluding CBD)	1.035	1.132
4. Lansing CBD employment	1.171	1.366
Combined factor for various trips[a]		
A-1 Meridian–Meridian	1.108	1.555
A-2 Meridian–East Lansing	1.094	1.332
A-3 Meridian–Lansing (in corridor)	1.084	1.324
A-4 Meridian–Lansing CBD	1.154	1.455
B-2 East Lansing–East Lansing	1.055	1.174
B-3 East Lansing–Lansing (in corridor)	1.046	1.167
B-4 East Lansing–Lansing CBD	1.113	1.282
C-3 Lansing–Lansing (in corridor)	1.017	1.064
C-4 Lansing (in corridor)–Lansing CBD	1.082	1.169

[a] Factors are computed as the square root of the population factor multiplied by the employment factor.

TABLE 6 Anticipated Distribution of Route 1 Bus Riders—2000 Weekday

Section (WB-off; EB-on)	WB-On; EB-Off (%) 1	2	3	4	5	6	7	Totals
1 Meridian-Mohawk	1.7							1.7
2 Mohawk-Hagadorn	3.3	-						3.3
3 Hagadorn-Charles	3.9	5.2	-					9.1
4 Charles-Harrison	3.9	5.1	6.6	-				15.6
5 Harrison-Homer	0.8	1.2	1.6	6.0	-			9.6
6 Homer-Grand	1.6	2.3	2.9	11.0	5.7	3.2		26.7
7 West of Grand	3.2	4.1	5.4	20.5	10.8	15.7	-	59.7
Totals	18.4	17.9	16.5	37.5	16.5	18.9	-	125.7

Note: Maximum accumulation = 67.5/125.7 = 53.7 percent; WB = westbound and EB = eastbound.

TABLE 7 Summary of Present and Anticipated Bus Ridership for a Typical Weekday—Base Condition

	Year		
Route	1980	1985	2000
1	5,470	5,940	6,876
Meridian Mall Express	300	346	436
13-15	465	503	544
Totals	6,235	6,789	7,856
Index from Table 6	1.00	1.09	1.26
Applying total average growth factor from Table 4	6,235	6,796	7,917
Index	1.00	1.09	1.27

Source: Michigan Department of Transportation, East Grand River Corridor Review Draft.

TABLE 8 Present and Anticipated Peak Hour—Peak Direction Bus Riders at Maximum Load Point in the Base Condition

Route	Year 1979-1980	Year 1985	Year 2000
1 East Lansing—Meridian Mall	300	330 (1.10)	390 (1.30)
Meridian Mall Express	75	90 (1.20)	115 (1.53)
13-15 Groesbeck	65	70 (1.08)	80 (1.22)
	440 (1.00)	490 (1.12)	585 (1.33)

Note: Figures in parentheses reflect ratio to 1979-1980 base.
Source: CATA Ridership Survey.

wise, the base case ridership forecast would not be realized.

2. Each option generally would provide the same basic service frequency between Meridian Mall and downtown Lansing. Running times reflect the transit service characteristics developed by the George Beetle Company (2).
3. An effective level of local service would be maintained between East Lansing and downtown Lansing under all options.
4. Schedules between Route 1 feeder services and the trolley bus, busway, and light rail services would be fully coordinated to minimize transfer times. A two-minute transfer time was assumed for these options.
5. Ridership in each of the seven sections along Grand River and Michigan Avenues was assumed to be concentrated at the easternmost point in each section.
6. Ridership growth in the Williamstown Express bus route--to east of the study area was not considered.
7. Fares would remain at 1980 levels ($0.35) in real dollars. A $0.50 fare, such as established in 1981, would reduce stated values by 7-8 percent, based on CATA's system-wide experience.
8. Parking charges in the Lansing and East Lansing CBDs would remain at present levels in constant dollars.
9. The real cost of gasoline would remain constant.
10. There would be no major shortages in gasoline.

Elasticity Factors

The percent change in the number of trips that occur in response to a 1 percent change in any of the "costs" of travel is called the demand elasticity. Thus, a 50 percent gain in ridership from a 100 percent reduction in travel time would reflect an elasticity of 0.5. The percent change in transit trips as a result of a 1 percent change in automobile parking or congestion costs is called the cross-elasticity.

The elasticity factors were based on current experience. They were as follows:

Elasticity

In-vehicle travel time	-.500
Headway	-.250
Fare (CATA experience)	-.267

Cross Elasticity

Automobile travel time versus busway and light rail	.500
CBD parking costs for work trips only	.450
Automobile operating costs	.180

Application of Elasticities

In applying these elasticity factors, it was necessary to make certain assumptions regarding transit travel times and headways for each option. Ridership estimations first assumed that headways would be generally similar for each option, and then were analyzed for differences in service frequencies.

Travel Time Changes

Table 9 gives the one-way in-vehicle travel times from downtown Lansing to Charles Street in East Lansing and Marsh Road at the Meridian Mall. Times are shown for the base condition, three bus options, a light-rail option, the existing express bus service, and automobile trips. A 2-min coordinated transfer in East Lansing is included in the trolley bus and light rail options.

TABLE 9 Estimated One-Way Travel Times To and From Capitol Avenue in Downtown Lansing

Alternative	To and from Charles (min)	To and from Meridian Mall (min)
Base condition	22.0	36.0
Low-capital bus	19.0	33.0
Trolley bus	17.0	33.0[a,b]
High-capital bus	12.5	26.5[b]
Light rail	11.5	27.5[a,b]
Existing express bus to Meridian Mall (schedule)	15	25
Automobile	8-11	14-17

[a] Assuming a 2-min transfer penalty.
[b] Using H.S. Levinson estimate of 14-min local bus schedule time between East Lansing (Charles Street) and Meridian Mall; from CATA Route 1 schedule, effective September 15, 1980.

The data show that in-vehicle automobile travel times are faster than transit travel times for all transit service options. The automobile also provides faster access times to the common line-haul sections--because (a) feeder bus service is infrequent, (b) there appear to be no park-and-ride sites along the line, and (c) there are no waiting times associated with car trips at the residential end of the line. For these reasons, the various transit options are not likely to attract motorists unless major increases in automobile disincentives are implemented.

Table 10 gives one-way in-vehicle travel times from downtown Lansing to the easternmost point in each of the previously defined sections. These comparative travel times were used with a -0.500 elas-

TABLE 10 Estimated One-Way Times From Lansing CBD (Ionia Street at Seymour Avenue)

Section	Base Condition	Low-Capital Bus	Trolley Bus	High-Capital Bus	Light Rail
CBD	-	-	-	-	-
Grand-Homer	11.0	9.5	8.5	7.0	6.0
Homer-Harrison	17.0	15.0	14.0	10.0	9.0
Harrison-Charles	22.0	19.0	17.0	12.5	11.5
Charles-Hagadorn	26.0	23.0	23.0[a]	16.5	17.5[a]
Hagadorn-Mohawk	31.0	28.0	28.0	21.5	22.5
Mohawk-Meridian Mall (Marsh Road)	36.0	33.0	33.0	26.5	27.5

Note: Travel times are from CBD to underscored street.

[a] Includes 2-min transfer time.

ticity to estimate ridership changes from travel time improvements.

The percent changes in travel time for each cell in the year-2000 trip matrix were estimated. The elasticity factor was then applied to these individual values to determine the changes in riders. In Table 11, all ridership is expressed in percentage terms, with the 1979-1980 total ridership equal to 100.0. Ridership was then summed for the Route 1 service, and the ridership for these other lines along Michigan Avenue was added. The resulting year-2000 ridership projections are given in Table 12. A similar procedure was used to estimate 1985 ridership. This led to the following weekday ridership estimates based on a $0.35 fare in real dollars and a 1979-1980 ridership of 6,235 passengers:

Case	Total Riders By Year 1985	2000
Base condition (with service adjusted to reflect growth)	6,800	7,860
Low-capital bus	7,100	8,200
Trolley bus	7,200	8,300
Busway	7,700	8,900
Light rail	7,750	8,950

Anticipated peak-hour peak-direction passengers at the maximum load point are given in Table 13. These estimates are generally based on existing peaking characteristics. However, it was assumed that peaks for the base service condition, improved bus, and trolley bus options would increase another 10 percent by the year 2000. High capital bus and light rail ridership estimates were increased by 25 percent to reflect both the additional peaking and larger person-capacity of articulated buses and light-rail vehicles. These latter adjustments produce ridership estimates that correspond to 15 percent of the daily riders passing the maximum load point in the heavy direction during the peak-hour. (As previously indicated, approximately 60 percent of the daily riders pass the maximum load point. Thus, for

TABLE 11 Percent Summary of Weekday Ridership Projections for Various Service Options in Michigan Avenue Corridor

		Year 2000 (% of ridership)				
Section	1980	Base	Low-Capital Bus	Trolley Bus	High-Capital Bus	Light Rail
Grand-Homer	13.0	18.4	18.5	18.5	19.1	18.9
Homer-Harrison	13.1	17.9	18.2	18.1	18.9	18.7
Harrison-Charles	13.7	16.5	17.0	16.8	18.3	17.7
Charles-Hagadorn	30.5	37.5	40.2	42.3	46.2	46.7
Hagadorn-Mohawk	13.3	16.5	17.2	17.7	20.1	20.1
Mohawk-Meridian Mall (Marsh Road)	16.4	18.9	20.2	21.0	22.4	23.5
Total	100.0	125.7	131.3	134.4	145.0	145.6

TABLE 12 Total Summary of Weekday Ridership Projections for Various Service Options in Michigan Avenue Corridor

		Year 2000 (total ridership)				
Section	1980	Base	Low-Capital Bus	Trolley Bus	High-Capital Bus	Light Rail
Grand-Homer, Homer-Harrison, Harrison-Charles, Charles-Hagadorn, Hagadorn-Mohawk, Mohawk-Meridian Mall (Marsh Road)	5,470	6,876	7,182	7,352	7,932	7,964
Meridian Mall Express	300	436	436	436	436	436
Routes 13-15	465	544	544	544	544	544
Total	6,235	7,856	8,162	8,332	8,912	8,944
Indices	1.00	1.26	1.31	1.34	1.43	1.43

TABLE 13 Anticipated Peak-Hour One-Way Riders at Maximum Load Point Based on Travel Time Changes

Year and Service	Base Condition	Improved Bus	Trolley Bus	Busway	Light Rail
1979-1980					
Route 1	300	-	-	-	-
Meridian Mall	75	-	-	-	-
Routes 13-15	65	-	-	-	-
Corridor Totals	440	-	-	-	-
1985					
Route 1	330	345	350	380	380
Meridian Mall	90	90	90	90	90
Routes 13-15	70	70	70	70	70
Corridor Totals	490	505	510	540	540
Adjusted Totals[a]	-	-	-	675[a]	675[a]
2000					
Route 1	390	405	415	450	450
Meridian Mall	115	115	115	115	115
Routes 13-15	80	80	80	80	80
Corridor Totals	585	600	610	645	645
Adjusted Totals	645[b]	660[b]	670[b]	805[a]	805[a]

[a] Includes 25 percent increase to reflect greater peaking in future years.
[b] Includes 10 percent increase to reflect greater peaking in future years.

Source: 1985-2000 Base Conditions are taken from Table 8; increased ridership for various options is based on ratios in Table 10.

8,900 daily riders in the year 2000, under the high capital bus and light rail options .15 x .60 x 8,900, or approximately 800 riders, would pass the maximum load point in the peak-hour peak direction trip.)

Fare changes

The preceding patronage estimates would be reduced 7-8 percent with a $0.50 fare (constant dollars) based on CATA's actual 1980-1981 experience.

Headways

All alternatives assumed that service frequency would be keyed to demand. In all cases, frequencies would equal or exceed current service frequency west of Charles. The higher ridership on the busway and light rail options would be absorbed by the larger capacities of the vehicles. Differences in frequency among the various options (7.5- to 10-min headways) coupled with a low headway elasticity (-0.25) suggest minimal ridership impacts. Consequently, no adjustments were made.

Sensitivity Analysis

Selected sensitivity analyses were performed to assess the effects of changes in traffic congestion, parking policy, and fuel costs and availability on potential transit ridership in the Michigan Avenue Corridor. These analyses drew on experiences throughout the United States as they relate to the Lansing-East Lansing situation.

Traffic Congestion

Travel growth of 26 percent by the year 2000 will substantially increase daily traffic flows along Michigan and Grand River Avenues and other streets in the corridor. Corridor peak-hour traffic growth will be slightly less, ranging from 15 to 20 percent overall. The additional traffic on Michigan Avenue will increase peak-period car and on-street transit travel times by up to 20 percent (i.e., an additional 1-2 min between Grand and Abbott, and another 1-2 min between Abbott and Meridian Mall).

Available cross-elasticity data give 0.32 for bus riders and 0.84 for rail rapid transit riders, assuming that transit is not affected by congestion (3). Elasticities of 0.4 to 0.5 have also been used in analyzing light rail transit patronage.

Accordingly, a cross-elasticity of +0.5 was applied to the busway and light rail options. An assumed 20 percent increase in corridor congestion here would yield a 10 percent gain in riders. Year 2000 corridor ridership would approximate 9,705 for the busway and 9,740 for the light rail. Anticipated year-2000 peak-hour one-way riders at the maximum load point would approximate 860. Thus, as automobile traffic becomes more congested, the light rail and busway options would become more attractive.

Parking

Stabilizing the downtown Lansing parking supply would produce up to 750 additional riders at the maximum load point; however, such a parking freeze was considered neither realistic nor practical. Moreover, it would seriously deter additional investment resulting in fewer transit riders than the preceding figures suggest.

Studies have suggested a cross-elasticity between transit ridership and parking rates of 0.51 for work trips and 0.38 for nonwork trips. Accordingly, a 0.45 factor was applied to 50 percent of the downtown Lansing's 15,000 parking spaces (3). State employee parking would account for 40 percent of the year-2000 supply, and an additional 10 percent of the spaces would continue to be available without charge as follows: (a) A 50 percent increase in parking costs (in constant dollars) would result in an 11 percent increase in corridor transit ridership; and (b) A 100 percent increase in parking costs (in constant dollars) would result in a 22 percent increase in corridor transit ridership.

Gasoline Price Increases

Automobile costs in 1990 will be slightly less than in 1980 because of greater fleet efficiency and stabilized fuel costs. However, automobile costs by 2000 could be 20 percent higher, assuming a high gasoline price scenario (4).

Cross-elasticities between increased transit ridership and automobile operating costs (excluding parking) have been reported as 0.21 for work trips, and 0.12 for non-work trips. That is, a 100 percent increase in fuel and automobile operating costs would result in a 12-21 percent increase in transit ridership (3). An elasticity of 18 percent and a real gas cost increase of 20 percent would result in a 3.6 percent gain in transit riders, in the study corridor; a 50 percent cost increase would produce a 9 percent gain. Consequently, increases in the cost of gasoline would not substantially increase corridor transit patronage unless unforeseen conditions occur.

Reduced Fuel Supply

A sustained fuel shortage could increase transit riding in the Michigan Avenue Corridor by 15-20 percent. This estimate is based on a 15-20 percent gain in Dallas (1973-1974) and 17 percent gain in Baltimore (1978-1979) (5,6).

Summary of Impacts

Anticipated year-2000 impacts of increased traffic congestion, parking supply constraints and costs, higher gasoline prices, and fuel shortages are given in Table 14. Because some overlap, the combined effects of several measures would be less than their sum.

Summary of Ridership Forecasts

The patronage estimates suggested for use in comparing alternative public transport systems are given in Table 15. These forecasts recognize that bus ridership would not keep pace with population and economic growth unless service is improved. The year-2000 ridership estimates for the light rail and high capital bus options reflect the impact of increased congestion. The peak-hour ridership estimates assume some increased peaking as follows:

- There were 6,235 daily riders in the corridor from 1979 to 1980. By 2000, assuming a $0.50 fare, ridership could approach 9,000 for some of the options.
- Peak-hour ridership was 440 in 1974 at the maximum load point. By 2000, this ridership could approach 800, assuming a $0.50 fare.

The ridership forecasts reflect the changes in activity anticipated in the corridor as of mid-1981. Faster rates of population and economic growth, concerted efforts to revitalize central Lansing, and expansion of State of Michigan employment and MSU

TABLE 14 Anticipated Effects of Traffic Congestion, Parking Constraints, Fuel Costs, and Shortages on Michigan Avenue Corridor Ridership

Impact	Percent Change	Percent Increase in Year 2000 Transit Riders	Transit Riders Affected
Automobile driving times	+20	+10	Busway, Light Rail options
Stabilizing downtown Lansing parking supply	–	+50	All options
Stabilizing state employee parking supply in downtown Lansing	–	15-20	All options
Downtown Lansing parking rates	50	11	All options
	100	22	All options
Increased gasoline costs per mile of travel	20	4	All options
	50	9	All options
Sustained fuel shortage	–	15-20	All options

TABLE 15 Summary of Daily Riders in Corridor

	No. of Riders by Year and Fare				
		1985		2000	
Alternative	1980, $0.35	$0.35	$0.50	$0.35	$0.50
Daily Riders in Corridor[a]					
Base service alternative					
Status quo	6,235	6,300	5,800	6,300	5,800
Service adjustment keyed to travel growth	6,235	6,800	6,260	7,860	7,230
Low-capital bus	6,515	7,100	6,530	8,200	7,540
Trolley bus	6,630	7,200	6,620	8,300	7,640
High-capital bus	7,120	7,700	7,080	9,700[b]	8,920[b]
Light Rail Transit	7,145	7,750	7,130	9,740[b]	8,960[b]
Peak-Hour Riders at Maximum Load Point in Corridor[c]					
Base service alternative					
Status quo	440	450	410	450	410
Service adjustment keyed to travel growth	440	490	450	645	590
Low-capital bus	460	500	460	660	610
Trolley bus	470	510	470	670	620
High-capital bus	500	675	620	860	790
Light Rail Transit	500	675	620	860	790

Note: Data are rounded. Fares are in constant dollars; riders paying a $0.50 fare = 92 percent of riders paying a $0.35 fare.

[a] Base condition (1979-1980) = 6,235 daily riders at $0.35 fare.

[b] Includes adjustment for traffic congestion.

[c] Base condition (1979-1980) = 440 daily riders at $0.35 fare.

enrollment could result in higher future ridership. Conversely, lower corridor growth could keep the ridership near existing levels. With no population growth, and no changes in fares, the high-capital bus and light rail options were estimated to attract 17 percent more riders than the base service condition.

Changes in Lansing's economy over the last 5 years suggest that the initial 1985 and 2000 population and employment forecasts were too high. Therefore, it is not likely that the year-2000 ridership forecasts would be achieved unless dramatic changes in the economy take place.

IMPLICATIONS

The use of on-and-off transit counts and travel elasticity data in conjunction with population and employment change provides a reasonable approach to estimating corridor transit ridership for various service options. While the data is site-specific, the techniques can be applied in other urban areas.

The method is realistic for existing or short-range growth. The effects of service improvements alone, 17 percent over base conditions, appear reasonable. The method assumes that transit system ridership would keep pace with population and employment growth in a corridor. Such a condition, however, does not always exist; therefore, a broader application would require analysis of trends in transit's market share, and application of appropriate adjustments to the forecasted future trip interchanges. Given such adjustments, the methods then can be applied to estimate the ridership impacts of fare, service, and travel time changes.

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Transit Service Contracting: Experiences and Issues

ROGER F. TEAL

ABSTRACT

Public transportation's fiscal problems have stimulated interest in service contracting as a strategy for improving the cost-effectiveness of service delivery. This paper contains a review of available evidence on transit service contracting with a particular focus on: (a) the extent of service contracting, including who practices it and the types of services involved, (b) the motivations for contracting, (c) the estimated costs and subsidy savings that can be realized from contracting, and (d) the major obstacles to this strategy. Available information indicates that transit contracting is a widely used strategy for supplemental DRT service and for small transit systems in states where state funds are available to subsidize transit. However, despite the impressive numbers of contracted services, they represent a small percentage of transit expenditures. The motivation for contracting is almost invariably financial, and contracting can save substantial sums. Compared to public agency operation, private sector contracting can produce cost savings of 15 to 60 percent, and subsidy savings of 50 percent or more. Resistance from transit, labor, and management to service contracting constitutes the major reason these large cost and subsidy savings have not induced more public agencies to contract. Management is reluctant to relinquish operational control, fearing a diminishment of service quality, and labor fears a loss of jobs.

The recent fiscal problems of public transit in many large metropolitan areas have stimulated interest in alternative service delivery systems for public transportation. One strategy, that of contracting with private providers for public transportation services, has received particular attention. Private sector contracting is viewed as attractive because of its cost and subsidy savings potential--savings of 25 to 50 percent of public agency transit operator costs have been cited (1-3). The reality, however, is that relatively little transit service contracting currently takes place and that substantial political, organizational, and legal obstacles confront plans to increase the use of this strategy. In addition, little detailed information is available on the extent of service contracting, its economic benefits, and the institutional factors that affect its feasibility.

The purpose of this paper is to provide a review of selected experiences and issues of transit service contracting. The paper focuses on five major topics:

1. How widespread is transit service contracting, who practices it, and what services are involved?
2. Why do public agencies engage in private sector contracting, and what are typical situations in which they do so?
3. What is the magnitude of the estimated cost and subsidy savings that have been realized from contracting?
4. What are the major obstacles to service contracting and when are they able to be overcome? and
5. What issues involving service contracting require additional research?

These topics are explored with primary reference to service contracting experiences in California. In California, large numbers of local governments contract with the private sector to provide a variety of public transportation services. In addition, local governments and transit agencies in Arizona, Michigan, Minnesota, New York, and Virginia have engaged in service contracting with interesting results. Their experiences are also included in this analysis. Although the data are by no means exhaustive, it is probable that the experiences included in this paper are representative of the types of service contracting that occur, the economic benefits of contracting, and the problems this strategy encounters.

THE SCOPE OF TRANSIT SERVICE CONTRACTING

Service Contracting in California

Contracting for public transportation services is a nationwide phenomenon, but it has been particularly prevalent in California. Because relatively complete information is available on service contracting in California, that state's experiences are used to indicate the relative magnitude of contracting, the types of services that are contracted, and the local government entities that are most likely to utilize this strategy.

As of mid-1984, it was possible to identify 204 individual public transportation services or systems in California that used a private transportation operator as service provider. The large majority of these private providers are for-profit transportation providers, although a small portion (less than 10 percent) are not-for-profit organizations that, in most cases, initially provided social service transportation. Table 1 gives a breakdown of these 204 systems by type of service, total expenditures for that service category, and average expenditure per contracted service.

TABLE 1 Expenditures for Contracted Public Transit Services

Type of Service	No. of Systems	Total Expenditures (million $)	Average Contract Expenditure ($)
Fixed-route transit	46	17,178	373,400
DRT and general public	79	18,117	238,700
DRT, elderly, and handicapped	79	14,481	183,300
All systems	204	49,768	244,000

To place this table in perspective, California contains approximately 375 public transportation systems, counting separate systems individually. [That is, a transit agency that provides both fixed-route transit and demand-responsive transit (DRT) would be credited with two systems.] During 1982-1983, approximately $1.3 billion was spent on public transportation operations in the state. Therefore, while although $50 million is being spent on privately contracted transit services, this represents less than 4 percent of all operating expenditures for transit in California. Because the contracted services are small scale in nature, they represent only a small fraction of the transit service delivery system, even though they comprise more than one-half of all public transportation services in the state. Virtually every large scale transit service is operated directly by a public organization.

It is unlikely that the magnitude of California's use of transit contracting can be extrapolated to the national level. A direct extrapolation would indicate nationwide expenditures of more than $500 million on privately contracted services, but the actual (unknown) amount is probably considerably less. The reason is that local governments in California are almost certainly more prone to engage in transit service contracting than their counterparts in most other states. This is the result of both California's tradition of private sector contracting for a variety of local services, and the cost-effectiveness incentives built into the state's transit subsidy program (4,5). Nonetheless, the evidence from California implies that transit service contracting is not a rarity, but, rather, a relatively common occurrence for small transit systems and supplemental DRT services. This service delivery mechanism probably accounts for at least $100-200 million in nationwide expenditures on public transportation.

Types of Privately Contracted Services

As Table 1 indicates, all types of public transportation services are contracted to private operators. DRT services are the most likely to be contracted, but 46 fixed-route transit services in California also use a private operator as service provider. Almost all of these are entire fixed-route systems, and in a few cases, commuter express service is the only contracted service. Outside of California, there are several important examples of fixed-route services being provided by private contractors. In Westchester County, New York, the entire transit system, which consists of 321 buses operating on dozens of routes, is operated by private carriers. In both Phoenix and the Tidewater, Virginia (Norfolk-Virginia Beach standard metropolitan statistical area) region, the regional transit agency contracts with a private transportation firm to operate small vehicles (vans or mini-buses) on low-density transit routes. In the Houston area, most of the regional transit agency's park-and-ride express services are operated by private bus companies in a large contract service that uses 113 buses. The Dallas transit agency has just initiated a similar contract service involving more than 60 buses.

Transit service contracting is most frequently practiced with DRT. In fact, public agency operation of DRT is rare in California. Of the 85 general public DRT systems in the state, only 6 are operated by public agencies. This is a nationwide trend. Even transit agencies that initially operated DRT themselves, such as in Rochester, New York, and Portland, Oregon, eventually turned the service over to the private sector because of excessive operating costs. Some transit agencies have even substituted DRT for unproductive fixed-route services. For example, Phoenix Transit replaced its entire Sunday fixed-route service with a privately contracted DRT system, and Tidewater Regional Transit (TRT) has terminated several bus routes and replaced them with DRT services.

Who Contracts?

In California, transit service contracting is most frequently practiced by general purpose local governments, that is, by cities and counties. The following table gives data indicating that nearly two-thirds of all contracting entities are cities, and another one-fifth are counties. Although a relatively small number of regional transit agencies engage in service contracting, they represent over 40 percent of all regional transit agencies in the state. Transit agencies typically contract only for DRT services--only two urban or suburban transit agencies contract for any fixed-route service and, in both cases, this is express bus service into San Francisco, which, historically, has been privately provided.

Contracting Entity	Number of Entities that Contract Out
Municipality	104
County	35
Transit agency	16
Others (e.g., joint power authority)	6
Total	161

California's experiences thus tend to support the widespread perception that transit agencies only rarely contract out for fixed-route service although they are much more likely to contract out for specialized DRT services. The few transit agencies that do contract out for any type of fixed-route service--for example, Houston's Metropolitan Transit Authority (MTA), TRT, Golden Gate Transit (GGT), and Phoenix Transit--have received considerable national attention specifically because they are so unusual. It is much more common for cities and counties to engage in service contracting for fixed-route transit. Of course, such local governments are also more likely to contract for all types of public transportation services.

MOTIVATIONS FOR TRANSIT SERVICE CONTRACTING

Local governments contract for public transportation services for two interrelated reasons: service contracting saves money, and it forestalls the need to create or expand a public bureaucracy to deliver a local service (4,5). Not only does this usually also save money, but, it also gives the local government more flexibility in adjusting the service output level. Public officials recognize that cutbacks in public agency-operated services tend to be difficult to achieve partially because of the political influence of public employees.

These benefits of contracting represent necessary but insufficient conditions for its utilization. Local governments are most likely to contract out either when they cannot afford a transit service otherwise or when the monetary savings that result from contracting can be used for other government purposes or to keep taxes low. These conditions do not exist for many transit operations, particularly large regional transit agencies. A major reason that transit service contracting is so prevalent in California is that the state's transit subsidy program is structured in such a way that most local governments have a strong incentive to consider the monetary implications of service delivery mechanisms.

In California, funds for public transportation subsidies are generated by a sales tax on gasoline, of which most of the proceeds are distributed back to the state's cities and counties in proportion to their contribution to gasoline sales. Except in the State's ten most populous (and most urbanized) counties, these local transportation funds (LTF) can be used for either transit or highways, provided that no unmet transit needs exist. That is, once a basic level of transit service is provided, a city or county can use the remaining LTF for streets and highways. Because funds for street and highway repairs are in continual demand, local governments have a strong incentive to maximize the portion of the LTF that can be used for that purpose. Local governments have determined that the most effective way of minimizing transit expenditures while still providing an adequate level of service is to maximize the amount of service contracting. In the 48 counties where the LTF can be used flexibly, private sector contracting by cities and the county for transit services is the norm, not the exception.

The propensity of California local governments to contract out for transit services in order to use public funds most efficiently exemplifies the incentive for cost-effectiveness created by nondedicated transit subsidies. When the funds used to subsidize transit can be used for other local government purposes and are not dedicated exclusively to transit assistance, service contracting becomes a much more appealing strategy. TRT and Phoenix Transit, two of the most active contracting agencies among regional transit operators, both use nondedicated local subsidies, as do many municipalities and counties around the country that contract out for transit service.

Powerful incentives for transit contracting are also created by a relative paucity of funds for transit, even when these funds are dedicated solely to transit assistance. Local governments in Michigan and Minnesota have made extensive use of transit contracting and, in both states, the major source of nonfederal subsidies is state funds that are subject to annual or biannual appropriation and are quite limited in magnitude. Cities in these two states cannot afford to pay a high price for transit service, for to do so would mean no transit service at all. Similarly, Los Angeles County is rapidly becoming a stronghold of transit service contracting as the result of a local transit subsidy program (funded by a one-half-cent sales tax increment), which returns substantial sums to the cities in the county, but not enough to enable them to afford expensive transit agency service. For example, a city with a population of 50,000 receives over $400,000 annually for community transit services from this subsidy program. This is enough to purchase a large amount of contracted service but represents only a meager amount of public operator service. Consequently, most communities that did not already have a municipal transit operator have contracted with a private provider for transit or paratransit services. There are now more than 25 privately contracted public transportation services in operation within the county.

One other motivation for employing service contracting is to implement transit services more rapidly than would be possible otherwise. The Houston MTA turned to private bus companies for its commuter express bus program when it became apparent that the transit agency lacked the buses and trained personnel to quickly respond to rapidly increasing demands for peak period service. Cities and counties in California often cite the lag time required to develop a public sector-operated service as an important reason to engage in service contracting. This factor is usually less significant, however, than expected cost savings from contracting and avoiding creating (or expanding) a public bureaucracy for transit service delivery.

Prototypical Service Contracting Situations: Regional Transit Authorities

Regional transit authorities have almost invariably contracted out for supplemental services--such as DRT, commuter express services, and low-density fixed-route services--when they have contracted out at all. Table 2 gives several examples of regional transit agency service contracting, including some of the best-known cases.

These transit authorities have engaged in service contracting for one of three reasons. TRT, Phoenix Transit, Omnitrans, and GGT face strong subsidy minimization pressures because of their use of nondedicated local subsidies. Orange County Transit Department (OCTD) has provided DRT service since its inception, and has always contracted out for such service because of a recognition that to do otherwise would lead to unacceptable costs. If OCTD wished to provide this service at all, and it was subject to strong community pressures for DRT, then contracting was a necessity. Houston's MTA contracted for its commuter bus service because this was the only feasible method of implementing the service in timely fashion, and the agency was under great political pressure to expand its peak period services.

In general, these transit agencies have established relatively clear-cut demarcation lines between services that are subject to contracting and those that are not. None of the agencies contract out with the private sector for all-day transit service using standard size transit buses. TRT, however, has contracted with one of its constituent local governments to provide fixed-route service in that city using TRT buses. TRT is also unusual in that it has converted unproductive bus lines to privately provided fixed-route van service--none of the other agencies have replaced their own fixed-route service in this fashion.

In fact, only TRT and Phoenix Transit have directly substituted any type of privately provided service for their own agency-operated services. Omnitrans, despite operating one of the largest paratransit contracting programs in the country, is resistant to proposals to convert agency-operated fixed-route services into privately operated fixed-route or paratransit services. This is in spite of the agency's farebox recovery ratio on some of its fixed routes being less than 10 percent, and the average subsidy per passenger being in excess of $4.00 on these routes. GGT is similarly uninterested in contracting out services it now provides. It plans to operate all additional commuter express service itself, even though the agency's unit cost for such service is more than 35 percent higher than that of the private bus companies it uses for its contracted subscription bus program. The major reasons that agencies have established fences around contract services are (a) potential labor problems, (b) perceived service quality problems with contracting out regular transit services, and (c) the antagonism of some transit managers to relinquishing operation of mainline transit service.

Prototypical Service Contracting Situations: Municipalities and Counties

Table 3 gives several examples of city and county transit service contracting. As is apparent, these

TABLE 2 Examples of Regional Transit Authority Service Contracting

Agency	Type of Services Contracted	Magnitude of Service Contracting
TRT	General public DRT, fixed-route with 3 vehicles	13 vehicles in 8 DRT modules; 2 fixed-routes
GGT	Commuter express (subscription)	27 buses on 15 routes
Houston MTA	Commuter express	113 buses on 13 routes
OCTD	General public DRT	130 vehicles in 5 regional DRT modules
Omnitrans	General public and specialized DRT	35 vehicles in 11 municipal DRT modules and 20 vehicles in 2 regional specialized DRT services
Phoenix Transit	General public DRT, fixed-route	3 DRT services with 20 vehicles; 1 fixed-route with 2 vehicles

TABLE 3 Examples of County and Municipal Service Contracting

Agency	Type of Services Provided	Magnitude of Service Contracting
Westchester County (N.Y.)	Entire fixed-route system	321 buses
Los Angeles County (Calif.)	Fixed-route, commuter express, and specialized DRT	30 fixed-route vehicles; 6 DRT vehicles
Yolo County (Calif)	Entire fixed-route system	12 vehicles
San Diego County (Calif.)	Fixed-route and specialized DRT	19 fixed-route vehicles, 5 DRT vehicles
El Cajon (Calif.)	DRT (entire local transit system)	22 vehicles
Carson (Calif.)	Fixed-route and specialized DRT	4 vehicles, subsidized taxi service
Hayward (Calif.)	Specialized DRT	Subsidized taxi service
Tucson (Ariz.)	Specialized DRT	12 DRT vehicles

local governments are likely to contract out for entire transit systems, not just supplemental services, although there is a considerable amount of contracting for specialized DRT services by cities and counties. These cities and counties typically use nondedicated local sources of subsidy, and thus have compelling fiscal reasons to practice service contracting. In addition, the California counties that contract out have no desire to operate public transit themselves, and the only question was whether they would contract with a private or public operator. Competitive bidding resolved this question in favor of the private sector, as the relevant public operators invariably submitted a much more expensive bid than the competing private providers.

El Cajon and Hayward are typical of literally dozens of California cities that contract out for either general public DRT or specialized service for the elderly and handicapped. Because they are located in large metropolitan counties, these two cities cannot use state transit subsidies for nontransit purposes. In neither case are the available funds so abundant that the city can afford expensive transit services. El Cajon, for example, would have to pay the regional transit agency more than 2.5 times as much per vehicle mile as it is charged by the taxi company that actually provides the community's DRT service.

The governments of Los Angeles and Westchester counties are among the largest general purpose governments in the country to contract out for transit service. Fiscal factors and a reluctance to become directly involved in transit service provision were the motivating factors in both cases. The Westchester County transit system is probably the largest contract operation in the United States, and one of the most interesting as well. Several private companies are involved in the system, each operating multiple routes and responsible for vehicle maintenance as well as vehicle operations. The contractors receive a fixed fee per mile for their services, provided that they meet certain performance standards (e.g., maintaining schedules). If performance is below par, the contractor's compensation is reduced. Los Angeles County contracts for much less service than Westchester County as its transit responsibilities are confined to unincorporated or unurbanized areas, but it has made no less of a commitment to this strategy. It contracts for all-day fixed-route service, commuter express service, and specialized DRT at costs far below comparable public agency-operated services. Both of these counties have contracted for transit service from the outset, and thus never confronted labor or management obstacles to this method of service delivery.

ECONOMIC BENEFITS OF SERVICE CONTRACTING

The economic benefits of transit service contracting are the primary reason for its appeal. Private sector contracting usually saves money compared to public agency operation of a transit service; however, the magnitude of the savings are subject to considerable uncertainty. Several comparisons of public agency and private operator service costs are presented here, but these comparisons must be treated cautiously. Only in the case where a private operator replaces or is a substitute for public agency operation of an entire public transportation service can any precision be attached to cost savings. For example, if public and private operators bid $40 per vehicle-hour and $20 per vehicle-hour, respectively, to operate a city's entire fixed-route transit system, then it is possible to conclude with high confidence that the municipality saved 50 percent by contracting.

In many situations, however, only a portion of a transit system will be contracted to private operator. In such cases, cost savings are less clear cut. This is because the cost to the public agency of operating the relevant service can only be estimated through the use of a cost allocation model, and cost allocation methods do not necessarily produce reliable estimates of avoidable or incremental costs. Consequently, in those cases where cost models are used to determine public agency costs, there may be an overestimation of cost savings that result from contracting. On the other hand, private operators are often required to supply the vehicles for a contracted service, and the absence of capital expenses in public agency service costs will lead to an underestimate of cost savings in these cases.

All-Day Fixed-Route Services

Table 4 presents six different cost comparisons of comparable public and privately operated fixed-route services. These services all operate the entire day--none are peak-period-only operations. As is apparent, substantial cost savings are indicated for private-sector contracting ranging from 22 to 54 percent of public agency unit costs. As might be expected, cost savings are greatest for regional transit agencies and lowest for municipalities. Small municipal bus operators typically have lower unit costs than regional transit agencies as a result of lower wage rates, lower peak-to-base ratios, and the ability to share overhead expenses with other municipal services. Even compared to such

TABLE 4 Difference between Public Agency and Private Contractor for Fixed-Route Transit Services *(1,3,6)*

Type of System	Cost Difference (%)	Basis of Cost Comparison
18 small municipal systems in California	-22	Direction comparison
Phoenix Transit bus route	-62[a]	Agency unit costs versus private service costs
Yolo County transit system	-37[a]	Competitive bids
TRT	-48	Agency unit costs versus private service costs
2 New York City suburban transit systems	-32	Direct comparison
San Diego County transit system	-34[a]	Competitive bids

Note: Data obtained from government agencies responsible for transit planning and provision, and from private operators.

[a] Cost savings are understated because a private contractor was responsible for vehicle provision.

TABLE 5 Estimated Cost Savings for Commuter Bus Services Operated by Private Contractors *(1,2,7,8)*

Public Agency Sponsor or Potential Sponsor	Cost Difference (%)	Basis of Cost Comparison
Golden Gate Transit[a]	-25	Private operator actual costs and cost models for public agency
Los Angeles County[a]	-38	Private operator actual costs and cost models for public agency
Houston[a]	-35	Private operator actual costs and cost models for public agency
Cleveland[a]	-58	Private operator actual costs and cost models for public agency
SCRTD[a]	-51	Analytical cost models
Boston (MBTA)	-50	Analytical cost models

Note: Data obtained from government agencies responsible for transit planning and provision, from private operators, and from a February 1984 memorandum written on the cost of peak-hour service by W. Cox of the Los Angeles County Transportation Commission.

[a] Cost savings are understated because a private contractor was responsible for vehicle provision.

municipally operated fixed-route services in California, however, similar privately contracted services are more than 20-percent less expensive.

Commuter Express Bus Service

Proponents of transit service contracting often cite commuter bus service as a particularly promising application of this strategy. As a supplemental service, commuter express operations are believed to avoid some of the labor constraints that confront contracting of all-day transit services, particularly for expansion of commuter service. In addition, the cost-saving potential of contracting for peak-period-only services is believed to be great as these are a transit agency's most expensive services due to severe labor inefficiencies. Table 5 gives data on cost comparisons for the relatively few commuter bus services that have been contracted to private operators, as well as data on cost savings estimates derived from studies of public versus private provision.

The studies and direct comparisons revealed that large cost savings are indeed possible with contracting, provided that enough service is involved to enable the public agency to reduce overhead expenses when contracting out existing services or to forego additional overhead expenses in cases of service expansion. If only one or two bus runs are contracted by a public transit operator, the savings will probably be minor or nonexistent.

The magnitude of cost savings also depends on whether or not the contractor must supply the vehicles. This is a common requirement for commuter services, but can add substantially to the private operator's costs as a result of the high costs of suitable buses and the difficulty of achieving other utilization of the vehicles. It has been estimated that the capital costs of the vehicles added as much as 30 percent to the service costs of private operators in Houston, where new or recent buses were required to be used by the contractors (2).

The following table gives a more detailed comparison of the cost and subsidy requirements for commuter express bus service provided by GGT and the private operators who furnish its contracted subscription service. At the time of this comparison, 27 buses were used in the subscription bus program, operating on routes of 20 to 60 miles in length. GGT's service costs were calculated by applying the transit agency's cost model to a route that was the same length as the average route in the subscription program. Other aspects of the two services were also similar. Because the 27 buses then involved in the subscription service represented approximately 11 percent of GGT's peak bus fleet, it is likely that the overhead expenses implied by the cost model would come into play if the transit agency were to take over the privately provided services or contract out a similar amount of commuter service. The indicated 25-percent cost savings and 50-percent subsidy savings are probably conservative, as the private operators must supply their own vehicles. Depreciation charges would add at least 5 to 10 percent to the private operators' total service costs (the buses are not new, having an average age of 10 years), whereas the transit agency purchases its buses with public subsidies and thus does not include depreciation in its operating expenses. Despite the conservative estimate of cost savings, this comparison indicates that GGT saves approximately 5 percent of its annual subsidy requirements by contracting for its subscription services rather than operating these services itself. (Note that the data in the table were obtained from Golden Gate Transit.)

Provider	Cost	Subsidy
Private Bus Company	$1,589,510	$ 575,480
Golden Gate Transit	2,123,260	1,167,790
Difference	533,750	592,310
	+33.6%	+102.9%

DRT

DRT is the transit service most commonly contracted out to the private sector. Because service contracting is so pervasive for DRT, it is difficult to identify publicly operated DRT systems for cost-comparison purposes. The scattered evidence that is available, however, indicates that large savings are also possible for this transit service when it is privately contracted. Table 6 reveals that cost savings of approximately 50 percent are the norm for regional transit agencies, and such savings may even be conservative as the agencies included are relatively low-cost by national standards. On the other hand, several of the comparisons involve the replacement of fixed-route bus services by small vehicle (van or mini-bus) DRT operations, and the added dispatching costs of the latter may be more than offset by the higher vehicle maintenance and fuel expenses for large transit buses. Nonetheless, the cost savings will always be large.

TABLE 6 Cost Savings for General Public DRT Services Operated by Private Contractors

Public Agency for Comparison Purposes	Cost Difference (%)
Phoenix Transit	–54[a]
Rochester-Genesee Transit Authority	–45[b]
Orange County Transit District	–49[a]
Omnitrans	–55[a]
TRT	–49[a]
4 municipal systems in California (compared to 21 taxi company operated systems)	–12[b]

Note: Obtained from agencies responsible for transit planning and provision, private operators, and from References 3, 6, 9, and 10.

[a] Represents DRT service costs versus bus service costs for comparable service areas.

[b] Represents comparable DRT services.

Large subsidy savings are also possible by substituting DRT for unproductive fixed-route services. Phoenix Transit estimates that it has saved $700,000 annually by substituting DRT for its Sunday fixed-route services (1). This represents nearly 5 percent of total agency subsidy. TRT has reduced subsidy per passenger by as much as 64 percent in particular conversions of fixed-route transit to privately contracted DRT (3).

Although much lower cost savings are indicated for municipally operated DRT services in California, this is because the few cities that operate their own DRT systems also engage in the same cost-reduction practices as private providers. They pay low driver wages, they use part-time labor, and they share overhead with other municipal services. These are not unionized transit operations, and thus all wage rates are more reflective of private sector conditions. In contrast, the small, municipally operated, fixed-route bus services cited in Table 4 are about twice as expensive as privately operated DRT. Thus, it appears that it is possible for public agencies to save upwards of 50 percent by contracting for DRT service. Even the most cost-conscious public operators cannot match the service costs of private providers.

INSTITUTIONAL OBSTACLES TO SERVICE CONTRACTING

There exist several potentially significant obstacles to transit service contracting. First, transit managers tend to view service contracting unfavorably. Second, transit labor unions are almost invariably strenuously opposed to contracting. Third, when subsidy sources are dedicated exclusively to transit, as is often the case for large transit agencies, transit policy makers usually lack the incentive to support contracting. Fourth, the service quality of private operators may be below public agency standards, creating dissatisfaction on the part of both the sponsor and transit riders. Fifth, finding a suitable private provider may be problematic, and maintaining a potentially competitive situation for contract renewals may also be difficult. Finally, although the monetary savings from contracting are impressive in percentage terms, they may not represent large enough dollar amounts (because such a small amount of service is contracted) to induce a transit agency to overcome other reservations concerning this strategy.

Whether these obstacles in fact become manifest depends to a large extent on the type of public agency that is responsible for public transportation provision. When this is a city or county, the actual impediments to service contracting are usually relatively minor, unless the local government has operated a transit service itself for some time. As California's experiences indicate, general purpose local governments tend to view transit service contracting favorably, and frequently engage in this practice. Moreover, when a transit operator is subject to direct policy and fiscal control by cities or a county, particularly those cities or counties that do not dedicate financial support to transit, the transit operator, too, may embrace service contracting. Westchester County and the City of Phoenix are directly responsible for their transit operations, and city governments in the Tidewater and San Bernardino regions directly determine the amount of transit service they receive and the amount of local funds that will be allocated to the transit agency. In all four cases, service contracting is used far more than the national norm.

In contrast, many of the potential obstacles to service contracting become manifest when a relatively autonomous transit agency is the local entity with the greatest influence over transit decisions. The most important of these obstacles are rooted in the monopoly organization of public transportation in most large American urban areas. Monopoly organization, particularly when combined with dedicated transit subsidies, insulates transit managers from economic or political pressures to stress cost-effectiveness when making service delivery decisions. Even without such insulation, many transit managers would prefer to provide all services with agency personnel in order to maximize the size of the organization (usually a determinant of political influence) and to ensure maximal control over service quality. This combination of institutional arrangements and management attitudes blunts incentives for service contracting, and can represent an insurmountable obstacle.

The monopoly framework for public transit has also created serious labor constraints to service contracting. Section 13(c) of the Urban Mass Transportation Act, originally designed to protect transit workers from being displaced by capital investments, has been transformed into a powerful labor bargaining chip for preserving a monopoly on all jobs associated with transit service provision. The model agreement in Section 13(c) tacitly endorses transit labor's claim on all transit jobs, and many local labor contracts explicitly verify this claim. Labor contracts can thus represent an absolute legal barrier to contracting, unless they can be changed through collective bargaining. Although Section 13(c) itself is not an absolute barrier to contracting, and tough-minded transit managers have been able to contract in spite of labor resistance, it is a rare transit agency that can engage in service contracting without a major struggle with its labor force. Unless strong management and policy support exists for contracting, the prospect of a serious battle with labor may be enough to sink this strategy before it can be given a hearing.

Because of the Section 13(c) situation, service contracting is virtually out of the question if transit workers will be displaced as a result. This tends to limit transit agency applications to relatively small increments of service. Even some of the bolder uses of contracting, such as the activities of TRT and Phoenix Transit, have not been of a magnitude to require the agencies to lay off workers. The few truly large contracting activities undertaken by transit agencies, notably OCTD's DRT program (130 vehicles) and the Houston MTA's express bus program (113 vehicles), do not represent replacements of agency services, but are new services instead. As they do to affect existing transit workers, such new services are by far the easiest to contract to the private sector. However, relatively few transit agencies have the fiscal resources for major service expansions.

Although the major obstacles to service contracting are most applicable to regional transit agencies, two other potential obstacles can affect any contracting entity. The first is the issue of the quality of the service provided by a private operator. Private providers may fall short of public agency expectations concerning service reliability because of their greater concern about keeping service production costs low. For example, the Southeast Michigan Transit Authority (SEMTA) has sharply reduced its use of contract services (it originally contracted for commuter express service and several DRT services) because of persistent service quality problems with private operators. Many of these problems were attributable to inadequate vehicle maintenance, which led to unreliable service. SEMTA staff believes that some contractors were simply not capable of providing the necessary quality of service, as they had never before operated in such a demanding service environment. TRT has also experienced service quality problems with its DRT contractors, and has tightened its contract requirements and administrative oversight in an attempt to prevent recurrences (6). On the other hand, other major sponsors of contract services have not experienced serious service quality problems, nor have the vast majority of cities and counties in California. Nonetheless, the fact that negative experiences do occur gives credence to the belief of many transit managers that service quality can be a problem in contracting.

The second potential problem is that of maintaining a suitably competitive environment to keep private contracting costs low. Private transportation providers with the necessary capabilities to operate a public transit service are often not abundant, particularly in small urban areas. Even in metropolitan areas, it is not uncommon for a public agency to have only one or two providers to choose from. For example, TRT was able to interest only one local transportation company in bidding on its contract services, and several of the largest DRT systems in California have never had real competition for the service contract.

The concern is that lack of competition could cause private operators to sharply increase their rates to the public agency. Although this may eventually occur, it does not appear to have become a serious problem to date. Service costs of most sole-source contractors are reasonable by national standards and far below comparable public agency costs. Private operators view contract revenues as desirable because they are a secure revenue source which, in most noncompetitive situations, they do not attempt to exploit (5). Occasionally, private operator rates do appear somewhat excessive (the Houston MTA initially paid all-day charter rates for its peak-period-only express services), but this does not appear to be a widespread problem. The public agency almost always holds the upper hand in contracting situations, as it can provide the service itself or encourage nonlocal firms to bid when the current provider attempts to exploit a monopoly position. Of course, private operator rates may be lower when many firms compete for a service, but the cost differential between public and private operators is typically so large that public agencies will find it advantageous to contract out in noncompetitive situations as well.

AREAS REQUIRING ADDITIONAL RESEARCH

This paper represents a reconnaissance of the current status and future potential of transit service contracting. As such, it does not delve deeply into some of the issues that are likely to determine just how widely this strategy will be used in coming years. It is possible, however, to identify three areas in which additional research is needed to help clarify the institutional feasibility and economic benefits of service contracting.

First, research is needed in determining the magnitude of the cost savings that result from service contracting. The cost comparisons assembled for this paper range from relatively sophisticated attempts to model public and private operating costs for the same service to straightforward but possibly misleading applications of agency cost models to commuter express services to comparisons based simply on unit costs for the same or similar services (1, 2,5,7, and 8; and a February 1984 memorandum written on the cost of peak-hour service by W. Cox of the Los Angeles County Transportation Commission). None of these approaches are without their deficiencies, although it is encouraging that they all yield estimates of cost savings that range from 20 to 50 percent. Improved approaches are necessary for more accurate estimation of the cost savings that would result from either contracting with existing public operator services or using private operators to provide additional transit services.

This need is most acute for supplemental services, particularly commuter express service, and for all types of substitution services. In these situations, cost savings are difficult to estimate because of the problem of accounting for relevant public agency overhead costs and, for commuter services, because of complicated labor scheduling interactions with off-peak transit operations. The magnitude of the research problem should be emphasized because cost models must: (a) be relatively straightforward to apply and not require substantial amounts of data, (b) adequately represent the cost implications of changing the inputs to the service production process as well as changes in the level of output itself, and (c) be capable of giving reasonably accurate estimates when applied at the route level of analysis and when used in analyzing different magnitudes of service contracting.

Research on cost differences is also needed to account for the effect of requiring private operators to supply the vehicles for a contracted service. For commuter express service, such effects can be profound--it is estimated that vehicle capital costs can represent as much as 30 percent or more of total private operator service costs in some situations (2,7). Without being able to take the vehicle cost factor into account, estimates of public-private cost differentials, such as some of those cited in this paper, will understate the private-operator cost advantage.

A second major area for additional research is determining how much of a deterrent to service contracting the labor situation in public transportation is. There can be little question that federal law, local labor contracts, and the desire of many transit agencies to have smooth labor relations all make contracting out quite difficult. Much too little is known, however, on why a few transit agencies are able to contract out for a variety of services whereas most of their cohorts are not able to contract out at all. Are labor constraints as much perceived as actual, or are they truly as formidable as they appear? How important are the generally unfavorable views of transit management toward service contracting in giving influence to labor opposition to this strategy? Is the incentive structure for transit service decisions as important as labor constraints in forestalling serious consideration of contracting? The answers to these and other related questions have major implications for the institutional feasibility of service contracting by relatively large transit agencies.

Finally, research is needed on the question of how best to administer a service contracting program while maintaining consistency with an overall agency objective of minimizing service delivery costs. Some transit agencies, such as OCTD, have established a bureaucratic structure to administer their contract services. Although this ensures high quality of service as well as provider honesty, it is also quite costly--OCTD's administrative costs for its DRT program are 24 percent of the cost of service provision. But informal contract management can lead to problems, as has been learned by TRT. It seems that there are a sufficient number of transit agencies now engaged in service contracting such that a comparative analysis of their experiences would yield valuable insight into the questions of how much, and what type, of contract management is necessary.

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Abridgment

Simulation of Transit Route Operations

UPALI VANDEBONA and ANTHONY J. RICHARDSON

ABSTRACT

Public transport managers and operators face increasingly difficult problems in providing adequate levels of service at reasonable social and financial costs. A greater demand exists for analytical techniques that would allow them to evaluate changes to operational strategies before committing themselves to implementation in the field. This paper contains a description of the development of a discrete event simulation model for the analysis of on-street transit routes. The structure of the model is described and details are provided of the types of events that are explicitly modeled in the TRAMS package. The input requirements are described, and the modular nature of the simulation model is highlighted. The various options for output format are described, including the use of a computer graphics real-time animation option.

This paper reports on the development of a simulation model (TRAMS: Transit Route Animation and Modeling by Simulation) for on-street light rail transit (tram) route operations. The model can easily by applied to LRT systems operating in their own right-of-way, but currently is unable to be used with high density bus transit systems operating on-street because of the presence of local overtaking and merging maneuvers in such systems. The model simulates vehicle maneuvers, passenger demand, and transit vehicle interactions with other traffic. The simulation program is based on the event-update method, which simulates individual events as they occur in chronological order. The model consists of a collection of forty events in the event-update process and contains a computer animation interface that allows the user to visually monitor the simulated service (1). The animation of the simulated service is useful in visual verification of the model and, furthermore, the animation assists the user in forming a qualitative opinion on the service.

In this paper, the inputs necessary for the model, the modeling framework adopted, and the outputs obtainable from the model will be described. A more comprehensive description of the model can be found elsewhere (2,3). The model has been applied in several situations to assess various operating strategies (4,6; also see paper by Vandebona and Richardson elsewhere in this record).

INPUT REQUIREMENTS OF THE TRAMS MODEL

The inputs required by the model can be grouped into three categories: (a) supply characteristics, (b) demand characteristics, and (c) operational commands (which are responsible for the management of the simulation process).

Supply Characteristics

The supply characteristics required include (a) descriptions of the route, (b) the transit vehicle types used in the service, and (c) the prevailing traffic conditions along the route that affect the operation of the transit service. A description of stationary nodes and internodal lengths provides the basic route characteristics required by the simulation program. The stationary nodes along the route consists of five types:

- stop nodes
- intersection nodes
- route-end-point nodes
- detector nodes
- subdivision boundary locations

Only the first four types of stationary nodes are required in the input, as the subdivision boundary locations are installed by the program itself. The route is finely separated into 10-m sections by setting up boundary markers along the route at 10-m intervals. These markers aid in reducing the uncertainty of forecasting tram events over long distances by bringing up a tram event at least once every 10-m length of the route. These boundary markers are of great assistance in the organization of the animation display to be discussed later.

All the stationary nodes (except subdivision boundary locations) should be identified with their distance along the route and their elevation (to facilitate the calculation of gradients). Other required information related to stationary nodes includes the types of tram stop classified according to their functional differences. A tram stop can be specified as a timetable check point where all trams must stop and wait until the scheduled departure time, or a mandatory stop where all trams must stop irrespective of passenger requests. However, at mandatory stops, the trams can leave at the end of the passenger servicing and need not wait until the scheduled departure time. Stops not belonging to these two categories are denoted as normal stops where trams may stop depending on the prevailing passenger demand. The timetables of tram dispatch times at depots and timetabled tram stops provide: the input required to (a) dispatch trams, (b) hold trams at check points, and (c) determine the route segments served by each tram.

For intersection nodes, the input should describe the type of intersection node, which could be a signalized intersection, an unsignalized intersection, or a pedestrian crossing. For traffic signal locations, it is necessary to provide data on signal phasings and timings and the type of signal control employed (currently the program can handle 10 different control strategies). If a public transport priority option is installed at a traffic signal, then the core green time required on other conflicting approaches is required.

Information related to opposing traffic as well as other traffic sharing the tram track is provided in the input as an extension to the description of intersection nodes. The interaction with other traffic is prominent in the neighborhood of intersection nodes because the trams are generally slower than cars and are seldom affected by cars except when the cars form a queue at an intersection. The information required for traffic sharing the tram track is (a) the traffic volume at the intersection, (b) the length allowed for the maximum queue (if not defined, the inter-intersection length will be used as the allowable maximum length), and (c) the proportion of traffic turning right (left in the United States). Opposing through-traffic flow volume and the number of opposing through lanes are also required in the program input for the purpose of evaluating the opposing through flow rate and, subsequently, the rate at which turning vehicles can filter through the opposing traffic. Public transport vehicle detectors are described according to their function (for data collection or for active priority control), placement (upstream, tram stop, or stop line), and operating characteristics (presence detector or movement detector).

In addition to the stationary nodes, there are a number of movable nodes also along the route. The end-of-vehicle-queue nodes will vary over time depending on the overall traffic conditions. An accelerating tram will have an end-of-acceleration-point along the route. A moving tram will have a next-decision-point set up along the route, where the decision to be made is either to maintain speed or to decelerate. Both the end-of-acceleration-points and the decision-points are variable along the route and are different for individual trams along the route.

With respect to transit vehicle characteristics, the program can handle up to five different types of tram in a given simulation session. Vehicles are described in terms of their seated passenger capacity, total passenger capacity (includes standing passengers), number of doors (which selects the service time model to be applied), passenger servicing rates, and tram velocity-acceleration profile.

Demand Characteristics

The program allows for variations in passenger demand along the route as well as with time of day. The simulation program requires the passenger origin-destination linkages to be identified in the form of an origin-destination matrix for a specified time period. Different origin-destination matrices can be input for different time periods of the simulation session. However, in the absence of origin-destination data, the program has the facility to synthesize such data from boarding and alighting information. Again, provision is allowed to incorporate variations with time of day.

As described below, the pregeneration section of the TRAMS package processes the previously mentioned data and produces a passenger list, which stores the characteristics of all passengers who use the service in the simulation based on stochastic generations. In some simulation experiments, it could be desirable to use a passenger list produced previously for the same network. Such a method would be especially useful for comparative studies of different system characteristics. Therefore, there are three different ways in which the passenger demand can be introduced to the program. The passenger demand could be described by an origin-destination matrix, by passenger boarding and alighting vectors (in which case, the program synthesizes the origin-destination matrix), or by an existing passenger list (in which case, the pregeneration program is no longer required).

PROGRAMMING METHODOLOGY

The event-update program methodology adopted in TRAMS closely follows the method outlined in Richardson (7). Each event processor simulates the event concerned and eventually establishes the types of events that should follow this event and the times at which those events are expected to occur. The program attends to one event at a time, and submits times and the nature of next events that are generated from a particular event to an event scheduler. The event scheduler simply orders all currently scheduled future events in chronological order. When a future event is submitted to the scheduler, it searches for the proper location for the new event in the currently available queue of events and inserts the new event in the event queue. This arrangement means that the event at the head of the queue is always the next event to be processed. A simplified flow chart of the event update process is shown in Figure 1.

There are 40 events currently implemented in the TRAMS simulation package, and these are given in Table 1.

Process of Pregeneration

An advantage of the simulation method compared to other analytical methods is that simulation allows the modeling of stochastic processes in a behaviorally realistic manner. Simulation will produce statistically varying outputs with different input seed values for random number generation.

Although the variation in the output measurements is of great importance to the transport planner, the variation in the input variables over different service options being simulated will produce difficulties in assessing the true difference between the different service options. For example, if a signal priority scheme is to be compared against nonpriority operation, then the planner would prefer to keep the same input patronage and constant input dispatch headways for both options for the preliminary comparisons. It would be difficult to estimate the short term merits of the compared services if those inputs were not kept constant over the options. In simulation, identical average input patronage for the different options may produce different passenger arrival times at tram stops reflecting the stochastic nature of the arrival mechanism. Therefore, such a simulation procedure would already have eroded the degree of control over some input variables that the planner would prefer to impose on different service options. The output will now partly reflect the

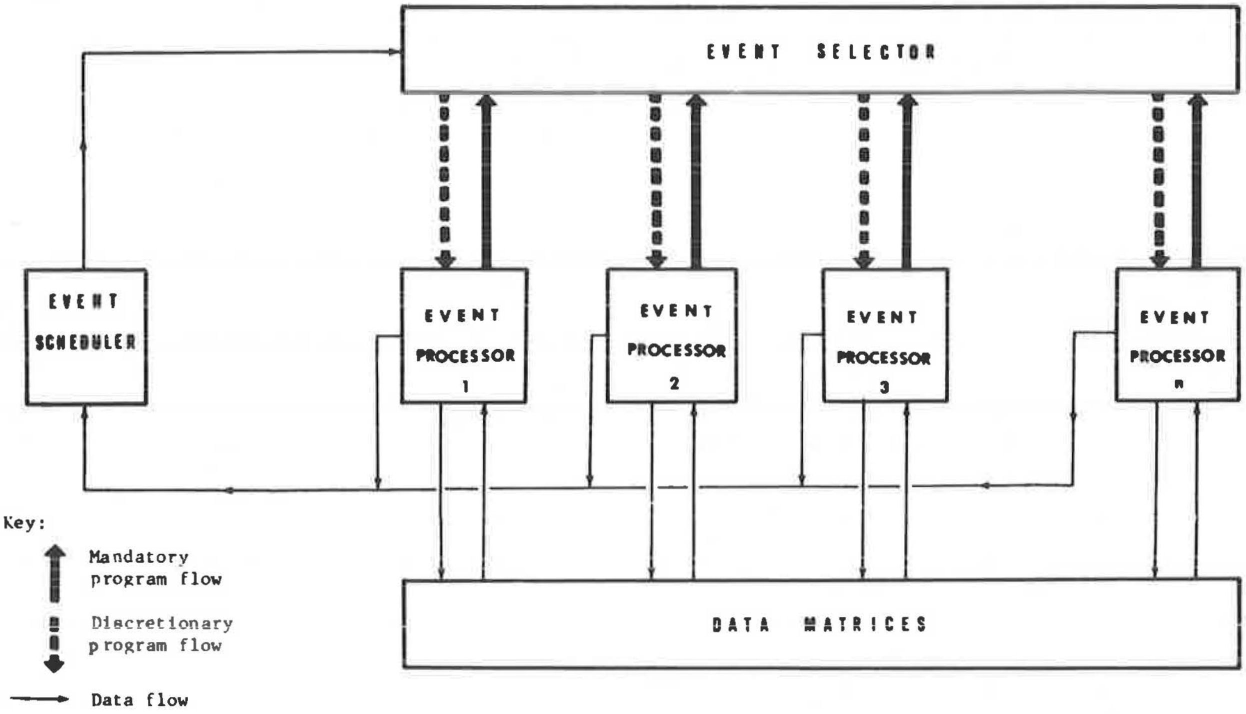

FIGURE 1 Flowchart of a general event-update simulation model.

TABLE 1 List of Possible Events in TRAMS Model

Event Number	Description
1	End of simulation
2	Traffic signal green phase begins
3	Traffic signal red phase begins
4	Tram departs from beginning of the route
5	Animation clock time increments
6	New passenger arrives at a tram stop
7	End of passenger boarding
8	End of passenger alighting
9	One second update time for data collection
10	End of passenger servicing
11	Tram reaches end-of-acceleration point
12	Tram arrives at tram stop
13	Tram arrives at traffic signal or an unsignalized intersection
14	Tram reaches boundary marker
15	Tram reaches merge point
16	Tram reaches end of the route
17	Tram reaches a detector
18	Tram reaches another tram in front
19	Tram reaches a car in front
20	A scheduled event is deleted
21	Tram departs from a tram stop
22	Tram departs from a traffic signal or unsignalized intersection
23	Car sharing the tram track is generated at the end of queue
24	Beginning of green for right turn arrow signal
25	Beginning of red for right turn arrow signal
26	Car crosses the intersection stop line
27	Tram restarts after the vehicle in front moves off
28	End of opposing through traffic saturation flow at traffic signal
29	Tram decision point for a tram in front
30	Tram decision point for a car in front
31	Tram decision point for end of the route
32	Tram decision point for a non-timetabled tram stop
33	Tram decision point for a timetabled tram stop
34	Tram decision point for a traffic signal or unsignalised intersection
35	Through car joins the downstream end of queue
36	Through car reaches a tram downstream of the intersection
37	Detection event by a detector
38	The beginning of opposing saturation flow platoon reaches a midblock intersection or pedestrian crossing
39	The end of opposing saturation flow platoon reaches a midblock intersection of pedestrian crossing
40	The end of opposing non-saturation traffic flow (i.e., the start of opposing zero traffic flow) reaches a midblock intersection or pedestrian crossing

variability generated for the different arrival times of passengers in the two options compared.

Therefore, an attempt has been made to provide the TRAMS user with the ability to maintain identical passenger characteristics and tram characteristics over different options. This is achieved by the pregeneration of the vehicle characteristics, dispatch headways, and passenger characteristics. The pregeneration creates an ordered list that includes the passengers who arrive at all stops on the routes to be simulated. The passenger origin, destination, and arrival time at the origin stop are stored in the passenger list. Tram dispatch times, vehicle characteristics, and driver characteristics are stored in the pregenerated vehicle list. Some deterministic features such as distance between stops and the list of routes served by each tram are also created at the pregeneration stage for later reference.

MODEL OUTPUTS

The model provides five different output options, which, in any given simulation, depend on the output option specified in the input operational commands. The output options are:

1. A detailed output that provides a summary of input specifications and pregenerated tram dispatch times. The passenger list created by the pregeneration session and later modified by simulation and data collected by data collection detectors are also in this category of output. This forms the base-level output option of the TRAMS package. The output at this stage is amenable to further analysis.

2. An animation option that displays the operation of the service by means of the computer animation interface. The animation interface monitors information on geographic characteristics, demand characteristics, and a digital clock related to the simulation. Figure 2 shows a reconstructed still frame from the animation display. Note that the letters indicate the following:

Letter	Meaning
A	Route
B	Intersection node in red phase (animation refresh feature)
C	Intersection node in green phase (animation refresh feature)
D	Unsignalized intersection node
E	Timetabled stop node
F	Nontimetabled stop node
G	Beginning of the route
H	End of the route
J	Transit vehicle location showing occupancy in tens of passengers (animation refresh feature)
K	Number of passengers waiting at the stop node (animation refresh feature)
L	Digital clock showing simulation time (animation refresh feature)
M	Detector node
N	Length of the route

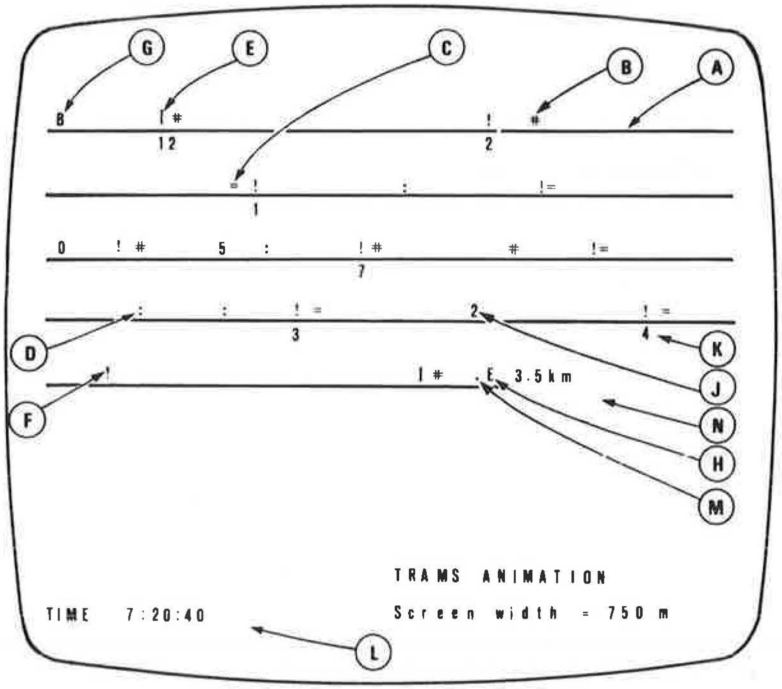

FIGURE 2 Reconstructed still-frame from the animation program.

The animation display is suitable for forming qualitative opinions concerning the service. In addition, this display is also found to be useful in validating the simulated behavior by visual observation. The animation output is displayed as the service is being simulated by the computer program. This method allows for future development of this interface to be able to handle keyboard instructions while the simulation is in progress.

3. An animation display with numerical information related to tram maneuvers and the passenger seat matrix forms the third output option available in the TRAMS package. This option is an extension of the previous option. When there are a number of trams on the display screen, this extended animation option loses its usefulness because of the increased amount of data output. For these reasons, this output option is considered to be suitable only as a debugging technique for program validation purposes.

4. An option that provides time-velocity and time-distance trajectory diagrams of individual trams. This output intercepts the program at the end of each 1-sec interval and retrieves tram speed and distance data to enable construction of these trajectories.

5. An option that yields quantitative measures of the level-of-service provided by the transit service. The analysis section of the TRAMS package computes these measures of level of service from the completed passenger list and from data retrieved by data collection detectors. These level of service measurements are converted into graphical format to observe the trends and variations in such measurements. The variations could be monitored along the route with local measures or across different operating strategies with the aid of global indices.

As the program monitors each tram in the simulation, it is possible to collect much more data by simulation than could be obtained by field surveys. The simulation data does not contain the human error component associated with field data collection. Although the simulation makes available a large amount of clean data, converting them into level of service measurements is hampered by lack of consistent definitions for the level of service. In the literature, the level of service of public transport operations has been measured and reported with different measuring devices, depending on the nature of available data and the nature of the analysis. Waiting time, travel time, vehicle occupancy, headway, deviations in headway, departure from schedule and generalized cost to passengers (8-11) are some features that are often measured in the analysis of level of service of public transport.

Considering the large amount of data available from the TRAMS package, the output measures from this package are not necessarily limited to the level-of-service measures indicated above. The analysis section of the TRAMS package can be readily modified to include further output measures according to the requirements of the program user. Currently, such output measures can be obtained by improvising Fortran program modules to further analyze the data matrices (i.e., passenger, vehicle, and detection lists at vehicle detector locations) created by the simulation section. In general, however, level-of-service measurements are based on three basic measures of public transport performance: travel time, comfort level, and reliability.

CONCLUSIONS

Computer simulation techniques provide a reliable and easy-to-operate model for the analysis of the level of service of transit operations. The model has the capability to output a range of level-of-service measures. Furthermore, the model outputs are available at different stages of processing, thereby aiding the explanation of the output results. For example, animation and trajectory diagrams can be used to supplement the implications derived from an analytical investigation of a particular treatment. As transit operations management decisions become more complex, and the revolution in computer technology makes computers more accessible and less expensive, computer simulation technology will play a greater role in transit route planning.

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Contracting for Public Transportation Services: Some New York State Findings

THEODORE A. THOMPSON and THOMAS J. CULLINAN

ABSTRACT

In fall 1983, the New York State Department of Transportation (NYSDOT) initiated an UMTA-funded study of barriers to private participation in the provision of public transportation services. Three counties, Onondaga, Westchester, and Suffolk, were to be analyzed concerning the current and potential involvement of private transportation firms in public transportation. Onondaga has a mostly public system with a few private operators, while Westchester and Suffolk make extensive use of private firms. Preliminary findings from the three counties concerning contracting indicate the following: (a) contracting with private operators has become the dominant institutional means of providing public transportation service where federal, state, and local subsidies facilitated the implementation of local economic preferences; (b) most public transportation contracts in New York are negotiated, not bid (however, this has produced no legal difficulties because of the contracting county governments with respect to the geographical limits of operating franchises held by private firms under the jurisdiction of NYSDOT's Regulation Division); (c) Incentive-based contracts, which are useful in promoting efficient operations, have so far not been implemented in New York; (d) the larger public transportation contractors tend to seek a greater role in local and regional planning and policy-making; and (e) performance evaluation by NYSDOT's Transit Division indicates that private operators under contract tend to perform more economically and efficiently, but less effectively than public sector operators in similar circumstances.

Performance of an UMTA-funded study of barriers to private sector provision of public transportation services at three study sites in New York has produced preliminary findings that are potentially relevant to other U.S. public transportation systems. These findings relate to:

1. The political and economic context conducive to contracting with the private sector,
2. The procedure for letting contracts,
3. The design of contracts for profits and performance,
4. The relationship between firm size and policy involvement, and
5. The application of performance measures to contracted operators.

New York's experience suggests that contracting with private operators for public transportation service can be efficient, economical, and effective, but that public sector administration of these contracts must ensure that the private operator's profit orientation does not slight the requirements of public service.

AN APPROPRIATE POLITICAL AND ECONOMIC CONTEXT FOR CONTRACTING

The three New York study sites are Onondaga, Westchester, and Suffolk Counties. Onondaga is in central New York and has a medium-sized city (Syracuse), extensive suburbs, and a diversified economy. Most intracounty public transportation in Onondaga is provided by a public authority that makes use of private operators only when unable to provide a needed service itself. In addition, a number of private firms operate a handful of intercounty commuter and specialized services with the county government providing the necessary subsidies from federal, state, and local sources.

Westchester County, which is north of New York City, is the residence of numerous New York City business people, contains a number of densely populated working class municipalities, and also has numerous national corporate offices. Suffolk County comprises the eastern one-half of Long Island at the end of the commuter rail lines and, while lacking a dominant urban center, varies from dense suburbs to rural farmland. These two counties provide essentially all their intracounty public transportation through contracts with private sector bus firms. These institutional arrangements for service provision resulted from specific political and economic contexts, an explanation of which follows.

Looking first at the oldest of the current systems, Onondaga County has the greatest proportion of public sector service. The Central New York Regional Transportation Authority (CNYRTA) was given a strong push toward public sector operation by its enabling legislation. This legislation facilitated the use of federal funds to purchase the existing transit bus operation that was incapable of further operations without subsidy. Legal ramifications aside, it would have been unreasonable for CNYRTA to use over $5 million of public funds to buy a private system and then not operate it, but instead contract with other private operators.

Of perhaps greater significance is the fact that in 1971, when CNYRTA was formed, there was no federal or state operating assistance available for private transit firms. In addition, the other three upstate public authorities were also forming operating subsidiaries as opposed to contracting for service with existing private operators. The New York City metropolitan area still had numerous private sector bus systems, but its scale of operations was considered too large to be a model for medium-sized upstate cities. Thus, CNYRTA's administration did not consider contracted private operation of the local transit system a viable option. State operating assistance became available in 1974, and Federal assistance in 1975. Both programs had provisions for aid to private operators giving Westchester and Suffolk Counties an increased range of institutional alternatives. CNYRTA's first board of directors initially intended to run the transit operation profitably regardless of how much service might have to be cut. A subsequent board appointee with years of experience in the New York City transit system was influential in reorienting CNYRTA toward the service responsibilities of a public transportation system in the public sector.

While although the preceding has indicated how CNYRTA brought Onondaga County's transit system into the public sector, a major factor in maintaining public sector operation is the skill with which it has developed support among those federal, state, and local agencies responsible for transportation planning and subsidies. CNYRTA is widely known for its facility in public and political relations. With external funding and significant influence over the local transportation planning process thus secured, external pressure for CNYRTA to contract with private operators is lacking. Given this pattern of development, it is ironic that CNYRTA's success in meeting some of its public service responsibilities has recently forced it to contract with taxi operators for elderly and handicapped (E&H) service.

When the mechanical problems of wheelchair lifts on 17 transit vehicles became too numerous during the winter of 1983-1984, CNYRTA stopped using these lifts. In order to serve the demand that had been generated in part by these accessible transit vehicles, CNYRTA shifted its wheelchair transportation commitments to its paratransit fleet. This fleet, however, could not handle this demand in addition to transporting the ambulatory E&H passengers. Consequently, CNYRTA contracted with taxi operators to transport a significant fraction of its ambulatory E&H patrons. Although this contracted service has cost less than CNYRTA's own service, the future of these contracts depends on studies that CNYRTA is conducting into the feasibility of resuming lift-equipped transit service.

Thus, a lack of significant influence favoring private sector operation when CNYRTA was established and a skillful development of good working relations with external funding agencies supportive of public sector operation have oriented CNYRTA to contract with private firms only when it cannot provide immediately necessary service itself. Public transportation contracting with the private sector undertaken by the Onondaga County government will be described later.

The political and economic context of Westchester County, whose public transportation system is the second oldest in the study, differed significantly from Onondaga County's. Its population density was triple that of Onondaga County; it had 16 private firms providing transit, express commuter, school, and charter services; and it had a strong private sector orientation indicated by the numerous offices of U.S. corporations. At the same time, Westchester County was not immune to the major trends affecting all U.S. transit systems in the late 1960s and early 1970s: sharply rising capital and operating costs combined with stable or declining farebox revenues.

The precipitating factor drawing Westchester County's disparate local transit operations into a unified system was the election of a new county executive in 1973. This executive hired a more aggressive transportation commissioner and convened a blue-ribbon panel to determine the best institutional means of providing public transportation. The panel concluded that contracting with private bus firms so as to subsidize operating deficits would be more cost-effective than a wholly public sector operation. Though the Metropolitan Suburban Bus Authority (MSBA) had recently been established as a subdivision of the regional Metropolitan Transportation Authority (MTA) to serve all the suburban counties, only Nassau County joined this authority. The corporate executives on Westchester County's blue-ribbon panel perceived public authorities as wasteful means of delivering public services. Consequently, Westchester County chose to provide public transportation and other public services by contract with private firms.

In constructing its first transportation contracts, Westchester County determined that it would guarantee both coverage of operating costs and a regulated profit to individual firms. In addition, the county would secure new vehicles through federal and state capital grants and lease them to the operators. The bus firms would then operate routes designated by the county transportation department following specified service quality standards.

By the time Westchester County had made its decision to keep public transportation in the private sector in 1976, state and federal operating and capital subsidies were available for distribution to both public and private operators. Public operators could receive federal and state assistance directly while private operators had to have local public sector sponsors. Westchester County subsequently considered putting its system under public management, but no steps toward implementing such a policy reversal were ever taken.

For a populous part-suburban and part-rural county, Suffolk was slow to develop a unified intra-county public transportation system. In fact, one large town had already started its own public sector transit system by the time the county government began organizing the county-wide system in 1979. Before this time, the county government had merely studied public transportation needs and acted as the local sponsor for state operating assistance for Suffolk County's private bus firms. A contributing element to Suffolk County's delay in organizing its public transportation system was the opinion of many residents that buses on residential streets were a nuisance they had hoped to leave behind when they had left New York City.

Suffolk County's decision to contract with private operators rather than establish a public authority was more pragmatic and less studied than Westchester County's. Suffolk County already had approximately 10 small operators providing uncoordinated local services throughout the county. The quickest, most economical way to coordinate these local services into a system was for county planners to design new routes connecting existing services and then contract for service on the new routes with current operators in the vicinity. By making use of existing operators, the county could avoid the lengthy tasks of setting up operational staffs and securing capital equipment.

Local transit service that was truly a system was thus established in Suffolk County with a minimum of new institutional structure. Subsequently, Suffolk County Operations (SCO), as the new system was entitled, has exceeded its ridership and farebox projections.

A consultant's recent evaluation of Suffolk County's system has recommended more tightly controlled cash collection procedures and a centralized maintenance facility (1). The latter would facilitate more uniform maintenance of the county-owned transit vehicles that are currently assigned in small groups to private operators throughout the county. Suffolk County is pursuing these recommendations in a manner consistent with its current operating philosophy, which advocates the least possible expansion of public sector institutional structure.

MEANS USED TO LET CONTRACTS

In Onondaga County, the county government contracted with a private operator for door-through-door wheelchair service in 1981 after CNYRTA demurred at providing this type of service. The first year's contract was negotiated, not bid. Though no challenge was made, the county purchasing agent determined that the county could be legally vulnerable and bids were solicited for the second year of operation. While although the costs of this service dropped immediately, the cost decline was produced not so much by the change to a bid contract as by respecifying the service to subsidize only the trips actually taken as opposed to hours of service provided whether used or not.

As indicated above, contracts with private operators, whether bid or negotiated, are the exception in Onondaga County. By contrast, contracts with private operators are the rule in Westchester and Suffolk Counties, but bidding on contracts is an exceptional procedure. The usual procedure is to negotiate contracts with specific operators. A competitive element may be introduced if Suffolk County negotiates with two firms both operating in the vicinity of a proposed route, but even this is the exception, not the rule.

The absence of public concern over negotiated versus bid contracts is due to the Westchester and Suffolk Counties transportation departments negotiating with those firms holding geographically appropriate NYSDOT operating rights in the areas where the counties plan to subsidize service. Some of these franchises are decades old. To date, potential competitors have respected these franchises and also realized the high cost of establishing transit service in areas where they lacked a service facility. When Suffolk County's contracts were sent to NYSDOT for funding approval in the early 1980's, New York's Division of the Budget objected to negotiated contracts as appearing to contravene the State's municipal bidding law (2). NYSDOT's Regulation Division responded that for Suffolk County to not have awarded the contracts as they had could have resulted in extended litigation with carriers already holding franchises in the areas of the routes being contracted. The Budget Division accepted this explanation. In addition, the argument was made that the carriers who were awarded the contracts were the most responsible carriers for those routes.

In defense of multiyear negotiated contracts, when a bus firm knows that it will hold its contract so long as it meets the county's cost and service quality standards, it is more receptive to long-range development projects such as driver and mechanic training and multiyear labor contracts with health and pension plans. Such projects promote stable, competent, safety-oriented labor forces--an important objective of the respective county governments.

DESIGNING CONTRACTS FOR PROFITS AND PERFORMANCE

To date, the types of contracts used by Westchester and Suffolk Counties to provide transit service have included profit for the operator with calculations based on revenues, expenses, or a management fee principle. Contracts incorporating performance incentives as part of the profit calculation have yet to be used in New York.

When Westchester County began contracting for public transportation services with private bus operators in 1974, profits were set at a percentage of farebox revenues. This worked to the operators' disadvantage when ridership decreases produced revenue declines. These ridership decreases resulted not so much from declines in service quality, which companies could control, as from prevailing social trends. Consequently, in the next series of contracts, 1978-1983, the profit allowed for each company was set at 6 percent of the expenses generated in providing the service requested by the county. Five years' experience with this method produced a negative response of a different kind--that a firm's profits increased as expenses increased (through either internal factors, such as wages, or external items, such as new service demands or increased fuel prices). The public thus perceived the private bus firms increasing their subsidized profits by means of increasing costs without an incentive for quality service or efficient operation.

As a result of this unsatisfactory situation with contracts calculating profits on both revenues and expenses, Westchester County began using a management fee concept. Under this arrangement, the term "profit" was not used. Instead, each bus company contracting with the county was provided a fixed management fee in lieu of profit. The level of this fee was established through analysis of previous operations such that no firm would receive a greater amount than its profit under the former revenue or expense calculations. The one large firm that performed 85 percent of the county's contracted service would have a 5-year contract in which the fee could be increased up to 50 percent of the increase in the regional Consumer Price Index (CPI) halfway through the contract term. The remaining small companies are expected to be put on a long-term basis in January 1985. Currently, all such management fees and any increases thereto are subject to NYSDOT's approval in addition to that of the county transportation department so as to prevent subsidized excess profits.

This management fee concept is not completely satisfactory to either the bus firms or the county government for analogous reasons relating to incentives. For the one large firm with the 5-year contract, for instance, the current contract has an incentive only to the extent that the firm works to prevent increasing costs from eroding its management fee.

This firm submits cost figures to the county's budget director annually. If the county's budget director objects to these cost figures, this firm may have its proposed budget submitted directly to the county's board of legislators where it has significant political influence. The board of legislators has final budget approval. Once an annual budget has been approved, the large firm is reluctant to provide any additional service proposed by the county transportation department during the budget year knowing that under the contract, additional costs will erode the profit percentage represented by the fixed management fee.

From a business perspective, such a position is logical, but it limits flexibility in service planning for the county's transportation department. Because this department is responsible for public transportation marketing, some conflict appears inevitable. The county transportation department wants effective service reaching as many people as is feasible while the carrier is more interested in economical and efficient service so as to protect its fees. One observer of this divergence in objectives terms it "creative tension" resulting in improved service to the public. Whether this claim of better service is confirmed by comparative performance measures will be considered later in this paper.

Another way of calculating profits for public transportation services involves incentive-based contracts. San Diego County, California, has incorporated incentives and penalties based on trips completed and on-time performance in its contracts with private operators. On-time performance is measured by random time checks performed by the county government (as stipulated in the County of San Diego's "Agreement for County Transit System to Provide Public Transportation Services" contract dated July 1, 1983). Contract negotiations in Westchester County, however, have so far not produced performance indices or measurement methods that are mutually satisfactory to the county government and the bus companies. For example, the county is not certain that when a bus operator calculates mean distance between road failures, it counts as failures those times when a replacement bus can pick up the route of a disabled bus with only a short delay.

Suffolk County compensates contracted carriers on a cost-plus-fixed-fee basis. The maxima for some 13 categories of costs are determined from the carrier's expense records with the county transportation department figuring in an inflation factor based on the regional CPI. These costs are generated by the provision of service on specific routes. The county then pays the carrier operating assistance on these figures subject to a final audit of the carrier's actual costs. If a carrier keeps its cost below the maxima established, it can increase its profit percentage, but not the amount of the fee. such a contract has negligible incentives toward efficient and economical performance. However, Suffolk County's private operators have responded positively toward this new system. Because SCO began in 1980, both the farebox recovery ratio and the passenger count have significantly exceeded projections while costs per mile and per hour have been held below national peers (see Table 1).

There is another type of contract designated 119-r in use in Suffolk County as well as other New York counties. This was the original contract format used in 1974 to distribute State operating assistance

TABLE 1 1982 Peer Comparisons—Suffolk County

Comparison Category	Suffolk County Operations	National Peer Group
Economy ($)		
Cost/vehicle-mi	1.56	2.17
Cost/vehicle-hr	24.47	33.44
Cost/passenger	2.12	1.49
Deficit/passenger	1.61	0.97
Revenue/cost	0.24	0.30
Efficiency		
Vehicle-hr/employee	1,370	1,066
Vehicle-mi/employee	21,485	16,946
Vehicle-mi/vehicle	41,436	33,736
Vehicle-hr/vehicle	2,642	2,203
Effectiveness		
Passengers/vehicle-mi	0.74	1.56
Passengers/vehicle-hr	11.54	25.20
Passengers/employee	15,817	25,918
Service quality		
Mean distance between failures (mi)	11,936	2,206

Note: The data in this table were derived from *1983 Final Performance Evaluation of Suffolk County*, Transit Program and Evaluation Bureau, Transit Division, New York State Department of Transportation. The peer group was composed of public transportation systems of similar fleet size from regions of similar population density and geographic extent. The statistics from outside New York were derived from Section 15 and American Public Transit Association data and phone calls.

to private operators through the intermediary of a county government sponsor. The State pays to the county sponsor an amount generated by the number of passengers carried and revenue vehicle-miles traveled by the private operator. Currently, the formula pays $0.18 per passenger and $0.47 per mile subject to discounting if the dedicated taxes providing the revenues for these subsidies fall short of projections. The county may also discount the subsidies slightly to cover its administrative costs before passing them through to the operators. If a county intends to distribute State subsidies in a radically different manner from the way the formula determines the money was generated, however, it must get NYSDOT approval for this alternative distribution.

In Suffolk County, the State subsidies provided under 119-r contracts in addition to farebox revenues have been sufficient to keep a number of routes in the well-populated sections operating. These are the routes that SCO was designed to link up.

If an operator should generate significant revenues through both the farebox and 119-r subsidies, NYSDOT has designed additional formulas to prevent the earning of excess profits. It should be noted that no Suffolk County operator has yet been "capped out" through this restriction.

FIRM SIZE AND POLICY INVOLVEMENT

In Onondaga County, CNYRTA dominates the public transportation policy and planning process. However, private transportation firms, despite their small size, assert their positions when public policy questions are considered. Public forums used by these firms to present their views include CNYRTA's annual public hearing accompanying its federal aid request, representation on the local metropolitan planning organization by a county government administrator who processes assistance applications for the private operators, and direct appeals to NYSDOT's commissioner when the private operators feel CNYRTA is expanding its competitive service offerings too rapidly. It is notable, therefore, that private firms in Onondaga County, despite their active role in the planning and policy process, seldom seek to increase the proportion of public transportation service provided by contracts with private operators.

In Westchester County, one bus firm provides approximately 85 percent of the contracted service and carries 95 percent of the passengers in the county. This firm receives over $8 million annually in operating subsidies from the county government using federal, state, and local sources. Such figures indicate this firm's dominance in the provision of Westchester County's public transportation. In considering this dominance, the executives of this firm seek a greater role in the public transportation policy and planning process of the county and region. The chief executive of this carrier has close political ties with some key county legislators and sits on the county Administrative Policy Committee, which meets monthly to discuss public transportation issues. The other members of this committee are county officials, including the county transportation commissioner. The Administrative Policy Committee and the Westchester County Legislature are the two primary institutions where the creative tension between private provider and public administrator mentioned earlier shapes local transportation policy. The expected UMTA policy on private sector participation in urban area transportation planning will probably have little effect on the county planning process, but may affect the regional planning procedure. The remaining small Westchester County firms are, with one or two exceptions, satisfied with the participation afforded them in the planning and policy process.

In Suffolk County, no one firm dominates the system as in Westchester County. In addition, for most Suffolk County firms, public transportation service is a small portion of their business. Suffolk County firms are primarily school bus operators, and the remainder are either municipal operations or commuter express services. Consequently, there is less concern with policy and planning matters among Suffolk County's operators than that expressed by Westchester County's dominant operator. Suffolk County operators are generally pleased that the county government has brought needed federal, state, and local capital and operating subsidies into Suffolk County's public transportation system and stabilized the revenues, secondary though they may be, from transit services. Thus, to date, these operators have not sought greater participation in the county's planning and policy process.

PERFORMANCE MEASURES APPLIED TO CONTRACTED OPERATORS

In Onondaga County, as mentioned earlier, the only significant amount of transportation service contracted for by CNYRTA was taxi service for ambulatory E&H passengers. Initial figures showed costs approximately $0.60 per trip lower for taxi service than for service by Coor-trans, CNYRTA's own E&H service. Comparative figures for the door-through-door service contracted by the county were not available. The county also signed contracts with two small intercounty private bus operators so as to provide them with state operating assistance. Calculations, which are not shown here because of their preliminary nature, indicate that these operators provided service more economically than CNYRTA largely because of lower wages. However, the calculations also indicate that the service was less effective than CNYRTA in terms of total passengers carried because of low passenger turnover on routes through rural areas.

In looking at the performance characteristics of the Westchester County system, the Transit Program and Evaluation Bureau of NYSDOT's Transit Division has compared them with characteristics of similar systems across the state and nation. Westchester's large private firm performs better than its state and national peers on most measures of efficiency and effectiveness. On measures of economy, the conclusion is less clear. The large Westchester County firm apparently performs better than both its New York State public sector peers and its national peers, particularly if lease costs on the maintenance facility are subtracted. The justification for subtracting such costs is that public sector operations usually have maintenance facilities financed by government grants. However, a question has arisen as to whether more of the county's administrative costs should be counted with this large firm's operating costs so as to make the comparison with public sector peers a more equitable one. If this were to be done, this firm's economy measures would deteriorate to the point where it would be closer to its state and national peers (see Table 2).

The next largest Westchester County firm provides only 7 percent of the county's contracted service with the remaining firms having even smaller roles. All of these firms are less efficient and effective than the one large firm largely because of less populous service areas. On measures of economy, the picture is mixed with the lower wages of the smaller operators offset by poorer farebox recovery ratios.

For most Suffolk County operators, their relatively low wage rates give them good cost per vehi-

TABLE 2 1982 Peer Comparisons—Westchester County

Comparison Category	Westchester's Major Firm	State Peer (public sector)	National Peers
Economy ($)			
Cost/vehicle-mi	3.06	3.98	2.94
Cost/vehicle-hr	38.68	41.84	37.82
Cost/passenger	0.93	1.25	1.04
Deficit/passenger	0.30	0.64	0.66
Revenue/cost	0.68	0.48	0.36
Efficiency			
Vehicle-hr/employee	1,190	971	1,118
Vehicle-mi/employee	15,020	10,210	14,370
Vehicle-mi/vehicle	30,388	26,410	25,908
Vehicle-hr/vehicle	2,407	2,511	2,017
Effectiveness			
Passengers/vehicle-mi	3.29	3.18	2.82
Passengers/vehicle-hr	41.53	33.50	36.22

Note: The data in this table were derived from *1983 Final Performance Evaluation of Westchester County*, Transit Program and Evaluation Bureau, Transit Division, New York State Department of Transportation. The peer groups were composed of public transportation systems of similar fleet size from regions of similar population density and geographic extent. The statistics from outside New York were derived from Section 15 and American Public Transit Association data and phone calls.

cle-mile and vehicle-hour figures, but their farebox recovery ratios and effectiveness measures, though exceeding projections, are weak when compared nationally largely because of the newness of the system and the low population density in the eastern two-thirds of the county (see Table 1).

SUMMARY OF FINDINGS

In New York, the examples of Onondaga, Westchester, and Suffolk Counties suggest that contracting with private operators has become the dominant institutional means of delivering public transportation service when federal, state, and local subsidies are available to implement local economic preferences. In addition, negotiated contracts have produced no legal complications because of the respective county governments that recognize the geographic limits of operating franchises held under the jurisdiction of the Regulation Division of NYSDOT. Further, though working toward incentive contracts that will reward achievement of specified performance measures, such contracts are not in place because of a lack of agreement over appropriate indices in Westchester County and the youth of the Suffolk County system. Current contracts in these two counties provide profits without considering performance. Transportation by service contract in Onondaga is so minimal as to make incentive contracts irrelevant. Fourth, though the sample size is admittedly small, New York's experience indicates that the larger the contractor and the greater the proportion of its business devoted to public transportation, the greater its desire to play a role in regional transportation policy and planning. Finally, the performance statistics of contracted firms indicate somewhat more economical and efficient, but less effective, operation than public sector transportation systems.

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A Basic Method for Estimating Future Faregate Requirements

GEORGE ROHRBACK and MATT du PLESSIS

ABSTRACT

The Bay Area Rapid Transit (BART) system may need to add faregates to its stations as patronage increases and headways are reduced in the future. A basic objective at BART has been the prevention of extended backlogs at the faregates. Essentially, patrons should be processed through the faregates at the same rate at which they arrive by train, or faster. This means that patrons from one train should be out of the station paid area before the next train arrives, that is, within the existing headway. To estimate the number of faregates needed in 1989 when patronage will have increased by 33 percent and headways are reduced to 2.25 min, the following steps were applied: (a) estimate the peak patron flows that will occur during the commute period, (b) calculate the time required for all passengers to exit each station, (c) develop exit time standards for different patronage levels and faregate conditions, and (d) calculate an index that weights the times a station does not meet the exit time standards. The index provides a single number to determine which stations will have the greater problems with patron delays. The study indicated that, based on 1980 patronage data, between 30 and 54 more aisles will be needed in 1989. However, depending on the type of equipment obtained, the actual number of faregate consoles required could be much greater.

Two important concepts to understand in reading this paper are the BART faregate consoles and the BART station centroids. A typical BART faregate array is shown in Figure 1. As indicated by the dashed lines, two faregate consoles make up one passenger aisle. The middle aisle is bidirectional and can be set by station agents for entry or exit, depending on the patron flow pattern. A centroid is a mezzanine area enclosed by faregates, service gates, railings, and a station agent booth. Stations within the BART system may have one, two, or three centroids.

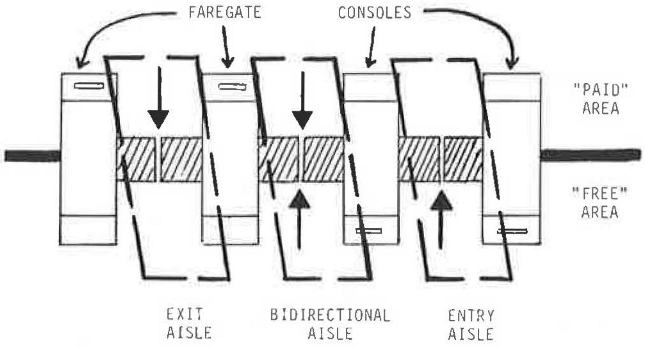

FIGURE 1 Typical BART faregate array.

BART is projecting that its patronage will increase by 33 percent in the next 5 years. At the same time, BART is planning to reduce its headways to 2.25 min in 1989. These two events will probably force BART to add faregates to its stations in order to process patrons within the headway time and thereby avoid long patron delays. The primary goal is to process patrons through the faregates at the same rate at which they arrive by train or at a faster rate. Patrons from one train should be out of the station paid area before the next train arrives.

Even with the current headways, some of the stations do not have enough aisles to process patrons in a timely manner, especially if two or three faregates are out of service. Conditions at the busy downtown stations and some of the end-of-line stations can become congested when a large crowd gets off the train during the commute periods. Shorter headways will therefore increase the need for more faregates. The purpose of the study was to estimate the number of faregates needed when shorter headways are implemented in 1989.

The actual number of faregates needed to avoid long patron delays was determined based on the following factors:

1. The projected peak number of patrons exiting a station from one trainload,
2. The time required to clear a station of all exiting patrons from one trainload,
3. The proposed time limits for clearing a station, and
4. An index for determining which stations have the more serious delay problems.

The index is a weighting factor of the occasions on which the exit time standards are exceeded and gives more importance to those occasions that are more frequent (e.g., all faregates operational). This report describes the four steps of the faregate analysis and shows how the number of faregates needed to avoid excessive patron delays at the faregates was estimated.

BACKGROUND

After several years of operation, It was found that some BART stations had significant delays at the faregates while other stations seemed to have no delays at all. One cause to which these differences can be attributed is that the patronage projections, on which the decision to install the automatic fare collection (AFC) equipment was based, were outdated--they had been made before the system opened in 1972. In many cases, the number of patrons using the stations was much greater or much less than the original estimate. A second cause can be attributed to reliability problems with certain AFC equipment installed in the busier stations. If two or three faregates were out of service, the patron delays would be extremely long. Sometimes the congestion became so bad that station agents would have to allow patrons to exit free, thus resulting in a loss of revenue for BART.

To ensure optimum use of all fare collection equipment and to reduce patron delays, the Management Services Division conducted a study in 1980 of BART's AFC equipment. Their objective was to develop a plan for relocating the AFC equipment in order to reduce patron delays at the busier stations. A secondary purpose was to reduce the number of unreliable faregate models used in the system.

A simple method was developed for analyzing the faregate requirements of each station. Exiting patron data was analyzed to obtain peak patron flow figures. Faregate capacities were determined and exit times were calculated for each station and centroid. Exit time criteria were also established. A special index was then developed as a tool for comparing the excess processing times. The study found that 10 stations did not comply with the exit standards. To eliminate all the instances of exit time criteria violations while at the same time removing most of the unreliable equipment, BART staff had to relocate nearly 100 faregate consoles. Sixty-nine consoles were moved to other stations and 27 were taken out of service. After the relocation project was completed, the number of failures per transaction dropped by 50 percent. The same methodology used in the 1980 study was used to estimate faregate requirements for the future. The following four sections of this paper describe each of the four steps of this method.

Patron Flow Rates

The first step in the determination of faregate requirements was to determine the peak patron flow rates that would occur during the commute period at each centroid. [These peaks occur when two rush-hour trains arrive at the station from opposite directions. Because all patrons are off-loaded almost simultaneously, the exit rush (7:00-9:00 a.m. at downtown stations, 4:00-6:00 p.m. at suburban stations) is considered to be a more critical case than the entrance rush.] In the 1980 study, the number of patrons whose tickets must be processed during these peak situations was determined using Data Acquisition System (DAS) 5-min traffic reports. Data from the 2-hr exit rush period was analyzed to determine both the highest patronage (worst case) and the 95th percentile for each station. The worst case patronage represented the largest number of patrons exiting during a 5-min period at each station during the days analyzed, while the 95th percentile was the level that was not exceeded 95 percent of the time during the 2-hr exit rush. These peak patron flows were used in the 1980 relocation design because the peaks were not expected to get much worse.

A complete reevaluation of projected patron flows is considered necessary, however, to provide a better basis for determining faregate requirements for 1989. The Research Division at BART has been requested to do a study of projected patron flows through the stations and through each centroid. Until those data are available, the 1980 data have to be used to provide a preliminary estimate of the magnitude of the problem.

Station Exit Time

By using the patron flow rates, the time required for all passengers to exit each station centroid can be calculated if the faregate capacity (number of patrons that can be processed per minute) is known. To establish the capacity of a faregate, stopwatch studies were conducted at Montgomery and Embarcadero stations (these are the two busiest stations in the BART system) to measure the flow rate of patrons through a faregate under queue conditions. The average processing rate measured for faregate equipment was slightly over 25 patrons per minute. Because this was determined from field observation, it is an actual rate that includes delays resulting from people inserting their tickets incorrectly or being underpaid and having to return to the addfare machine. The exit time was then calculated by dividing the patron flow rates by the centroid faregate capacity (number of aisles one-way multiplied by 25 patrons per minute per aisle). The calculated exit times for all station centroids are shown in Table 1. Exit times were also calculated with one faregate out of service at each centroid. This condition was analyzed to ensure that sufficient equipment redundancy exists at each centroid to prevent serious queuing problems from developing when equipment failures occur.

Exit Time Criteria

To provide a reference for evaluation of the calculated exit times for each station, exit time standards were developed. The exit time criteria given in the following table are based on anticipated headways in 1989.

	Time for Patrons to Exit (min)	
	95th % 2-Hr Rush	Worst Case
All Faregates Operational for All Lines	2.0	2.2
One Faregate Out of Service		
M Line (San Francisco-Daly City)	2.2	2.2
K Line (downtown Oakland)	2.2	2.2
A Line (Fremont)	2.2	3.0
C Line (Concord)	2.2	3.0
R Line (Richmond)	2.2	3.0

The basic standard was set at 2.0 min. This is the maximum desirable exit time with all gates operational for the 95th percentile patronage level. The 2.25-min headways on the M and K lines and intermittently on the R line were the basis for the 2.2-min standards. The longer headways on the A, C, and R lines allow the maximum permissible exit time to be set at 3.0 min. Although the headways on the A and C lines will actually be 4.0 min or greater, the need for equity on all lines favors using the 3.0-min standard for the A, C, and R lines. The possibility does exist, however, of changing the standards on these lines, especially if management feels the number of faregates mandated by these stringent standards is excessive.

Noncompliance Index

As a further tool, a noncompliance index (NCI) was formulated to provide a numerical tool for compari-

TABLE 1 Station Exit Times

Station/Centroid	Aisles 1 Way	Exit Time (min)			
		All Faregates Working		1 Faregate Out of Service	
		95 Percent Patron Level	Worst-Case Patron Level	95 Percent Patron Level	Worst-Case Patron Level
Lake Merritt	4	.7	.9	.9	1.2
Fruitvale	3	1.6	2.3	2.3	3.5
Coliseum	9	.3	.3	.3	.4
San Leandro	3	1.2	2.2	1.7	3.3
Bayfair	4	1.5	2.3	2.0	3.1
Hayward	3	1.6	2.2	2.4	3.3
South Hayward	2	1.9	3.2	3.8	6.4
Union City	4	1.5	2.0	2.0	2.7
Fremont	6	1.2	1.7	1.5	2.0
Rockridge	2	2.1	2.6	4.1	5.2
Orinda	3	1.5	2.6	2.2	3.8
Lafayette	4	1.4	2.1	1.9	2.8
Walnut Creek	5	1.8	2.5	2.3	3.1
Pleasant Hill	4	2.8	3.6	3.7	4.8
Concord	5	2.8	3.5	3.5	4.4
12th Street					
North	2	.7	1.1	1.6	2.2
Central	4	.9	1.3	1.1	1.7
South	2	.4	.6	.8	1.2
19th Street					
North	4	1.5	2.4	1.9	3.2
Central	2	1.4	2.4	2.9	4.8
South	2	.6	1.0	1.2	2.0
MacArthur	2	1.4	1.6	2.8	3.3
Oakland West	2	1.6	2.8	3.3	5.6
Embarcadero					
East	6	2.1	3.0	2.6	3.5
West	7	2.3	3.2	2.7	3.7
Montgomery					
East	8	1.5	1.7	1.7	1.9
West	10	2.3	2.6	2.5	2.9
Powell					
East	4	.5	.7	.7	.9
West	4	2.0	2.4	2.7	3.2
Civic Center					
East	4	1.2	1.9	1.5	2.6
West	4	1.6	2.6	2.1	3.5
16th/Mission	3	1.0	1.6	1.6	2.4
24th/Mission	4	1.6	2.6	2.1	3.4
Glen Park	5	1.7	2.5	2.2	3.1
Balboa Park	5	1.6	2.7	2.0	3.4
Daly City	8	2.5	3.2	2.9	3.7
Ashby	2	.8	1.3	1.7	2.5
Berkeley					
North	2	.1	.2	.2	.3
Central	4	.9	1.5	1.1	2.0
South	–	–	–	–	–
North Berkeley	2	1.0	1.9	2.1	3.5
El Cerrito	2	1.7	3.1	3.4	6.2
Del Norte	4	1.6	2.4	2.1	3.3
Richmond	2	1.4	2.3	2.9	4.5

son of exit time criteria violations. The NCI was developed by applying a weight factor to the exit time criteria violations. The weight factor is used to give a higher importance to the criteria violations that occur most frequently. Because the 95th percentile patronage level occurs more frequently than the worst case and all faregates are normally operating, this condition was arbitrarily given a weight of 4. Conversely, the situation in which the worst case patronage level is reached when one gate is out of service is the least likely condition and therefore was given a weight of 1. Obviously, the higher the NCI the more serious the exit time criteria violations. NCI is calculated by subtracting the exit time criteria (in minutes) from the station exit time (in minutes) and multiplying that by a weighting factor. The following calculation is for all faregates operational at the Pleasant Hill station:

95 percentile patronage:

(2.8-2.0) x 4 = 3.2.

Worst-Case patronage:

(3.6-2.2) x 3 = 4.2.

The following calculation is for one faregate out of service at the Pleasant Hill station:

95 percentile patronage:

(3.7-2.2) x 2 = 3.0.

Worst-case patronage:

(4.8-3.0) x 1 = 1.8.

The total NCI factor for the Pleasant Hill station, thus, is 12.2.

The NCI for the 26 stations expected to be in violation of the 1989 exit time criteria and the projected system total are given in Table 2. Although every station on the M line registers an NCI, the worst problems are expected at the Pleasant Hill and Concord stations. The system NCI of 110.7 gives an indication of the magnitude of the problems anticipated to occur in 1989 with the increased patronage and shorter headways. In the 1980 AFC Relocation Study, the NCI was found to be 22.4.

TABLE 2 Stations Not Complying with Exit Time Criteria

Station/Centroid	Noncompliance Index
Fruitvale	1.0
San Leandro	.3
Bayfair	.4
Hayward	.7
South Hayward	9.6
Rockridge	7.6
Orinda	2.0
Walnut Creek	1.2
Pleasant Hill	12.2
Concord	11.1
19th Street	
North	1.6
Central	4.6
MacArthur	2.3
Oakland West	7.4
Embarcadero	
East	4.9
West	6.7
Montgomery	
West	3.7
Powell	
West	2.6
Civic Center	
East	.4
West	2.5
16th/Mission	.2
24th/Mission	2.4
Glen Park	1.8
Balboa Park	2.7
Daly City	7.9
North Berkeley	.5
El Cerrito	8.3
Del Norte	.9
Richmond	3.2
System total	110.7

NUMBER OF FAREGATES NEEDED

The estimation of the number of faregates needed depends on the amount of reduction desired for the system NCI. For example, two levels of reduction are given in Table 3--(a) completely eliminate the NCI and (b) reduce the total NCI to less than 10.0. Fifty-four aisles are required to eliminate the NCI, while only 30 aisles are required to reduce the NCI to less than 10. The plot of faregates needed to reduce the system NCI is shown in Figure 2. As can be seen from Figure 1, 10 additional faregates could reduce the NCI to almost 50, and 40 additional faregates would only reduce the NCI to approximately 5. The plot graphically shows that adding more faregates has a decreasing impact on reducing the NCI. Again, the critical issue is what level BART wants to reduce the NCI to. Or, in other words, what degree of patron delays at faregates is BART willing to accept? As previously indicated, the exit time criteria could be made less stringent for the A, C, and R lines and thereby reduce the number of faregates needed on the system.

An important consideration in determining the number of faregates needed is the type of faregates to be added. BART would seek to find AFC equipment that would be compatible with the current system and that would also have high reliability. The critical issues would be the flexibility of the equipment and the number of consoles required to achieve single aisles. For example, the use of two faregate consoles for each initial aisle added to a station could almost double the number of equipment pieces needed. Twice the equipment needs means twice the cost.

TABLE 3 Estimated Number of Aisles Needed to Eliminate or Reduce the System Noncompliance Index (NCI)

	No. of Aisles Required	
Station/Centroid	To Eliminate All NCI Factors	To Reduce System NCI to Less Than 10.0
Lake Merritt	–	–
Fruitvale	1	–
Coliseum	–	–
San Leandro	1	–
Bayfair	1	–
Hayward	1	–
South Hayward	2	1
Union City	–	–
Fremont	–	–
Rockridge	1	1
Orinda	1	1
Lafayette	–	–
Walnut Creek	1	1
Pleasant Hill	3	2
Concord	3	3
12th Street		
North	–	–
Central	–	–
South	–	–
19th Street		
North	2	1
Central	2	1
South	–	–
MacArthur	1	1
Oakland West	2	1
Embarcadero		
East	3	2
West	4	3
Montgomery		
East	–	–
West	3	2
Powell		
East	–	–
West	2	1
Civic Center		
East	1	–
West	2	1
16th/Mission	1	–
24th/Mission	2	1
Glen Park	2	1
Balboa Park	2	1
Daly City	5	3
Ashby	–	–
Berkeley		
North	–	–
Central	–	–
South	–	–
North Berkeley	1	–
El Cerrito	2	1
Del Norte	1	–
Richmond	1	1
Total	54	30

CONCLUSIONS

The increased patronage and the shorter headways to be implemented in 1989 will create the need for additional faregates. These additional faregates will help to eliminate or reduce the patron delays at the gate arrays. The primary objective is to

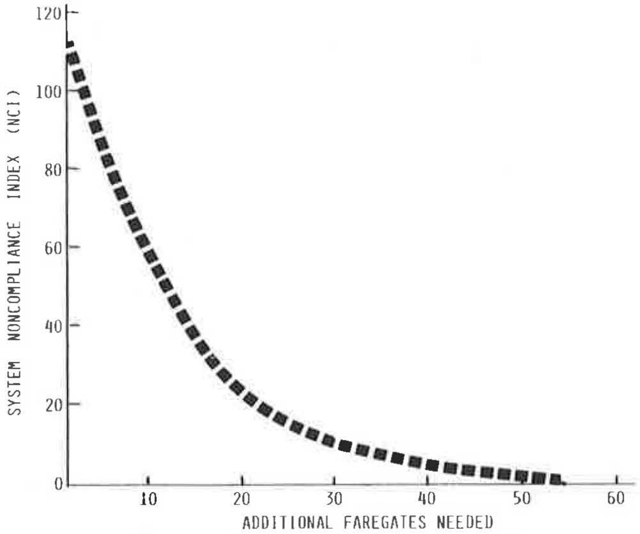

FIGURE 2 Additional faregates needed to reduce system noncompliance index.

ensure that the delays at the faregates do not exceed the headways. Based on the 1980 data, the estimated number of additional aisles needed to avoid patron delays in 1989 will probably be between 30 and 54. The actual number of faregate consoles required will be affected by the revised patronage projections for 1989 and the type of AFC equipment selected to augment the present system. These two factors could easily cause the required number of faregate consoles to double. At the same time, the exit time criteria established for the various lines have a significant impact on the number of additional faregates needed. Fairly stringent criteria were used in the current analysis to maintain equitable conditions for all the lines. Changing the exit time criteria on those lines with longer headways would reduce the number of faregates needed on the system by 20 percent or more.

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Planning an Integrated Regional Rail Network: Philadelphia Case

VUKAN R. VUCHIC and SHINYA KIKUCHI

ABSTRACT

Regional (commuter) rail systems, which serve the growing suburban areas, have had increasing ridership in many cities. In response to this growing need for high-quality regional transit service, many European and Japanese cities have upgraded their old commuter lines into regional rail systems with diametrical networks, regular schedules, and services integrated with local transit. Completion of the Center City Tunnel in Philadelphia in late 1984 connected two previously separate sets of lines (Western--formerly Pennsylvania and Northern--formerly Reading), combining them into an integrated regional rail system. The methodology, process, and major results of the planning for the regional rail systems are presented in this paper both in general terms and in their application to the Philadelphia system. Analysis of passenger requirements, operational factors, and economics has shown that the radial lines should be converted into diametrical (through) lines with fixed train routings and clear designations (such as R-1, R-2, and so forth). Extensive data concerning the system's physical characteristics, operations, and passenger volumes were collected and presented in many tables, charts, and diagrams. An elaborate methodology for selecting line pairs was developed. The guidelines for pairing included balancing of capacities and frequencies, minimizing track path conflicts, considerations of potential for through travel, capacity of tracks on the trunk section, operational characteristics of the two connected lines, and so forth. The recommended set of lines is presented with the basic data concerning its lines including their lengths, cycle times, headways, and train consists for peak and off-peak hours.

Spatial spreading of our cities has resulted in longer commuting among different points throughout metropolitan areas. For many years, the dominant opinion was that the automobile was the best mode for serving all regional trips and that transit services were being neglected by riders. However, in spite of this neglect, most regional (commuter) rail systems have recently demonstrated their strong ability to attract riders. There are two major reasons for relative success and increasing need for regional rail transit: (a) regional rail lines serve the areas of greatest growth--outlying suburbs of major cities, (b) high speed, comfort, reliability, and safety make these systems more competitive with the automobile than most other transit modes.

Although the strong ability of regional rail systems to attract ridership has now been demonstrated, the systems have, in most cities, faced severe financial problems and their role has remained far less important than their potential would indicate. Our regional rail systems carry several times fewer passengers than comparable systems in many cities in other countries, such as Cophenhagen, Hamburg, Munich, Sydney, and Toronto. The reasons for this underutilized potential and for the financial problems lie in the fact that the characteristics of regional rail systems in most of our cities have not changed much from those of the commuter railroads, which they used to be (decades ago).

This paper contains a summary of a major study that was made to provide information to be used in integrating two separate rail systems into one regional rail system in Philadelphia (1). In the process, the differences between commuter railroads and regional rail systems were defined and are included. Extensive data on physical, operational, and ridership characteristics of the Philadelphia system are also included, but the major emphasis is on the methodology for planning the new network: determination of line pairings (i.e., how the former radial lines should be interconnected into diametrical ones).

THE EVOLVING CONCEPT OF REGIONAL RAIL

Commuter Railroads' Networks, Service, and Role

Traditionally, most large North American cities had a number of commuter rail services provided by several railroad companies. Their radial lines terminated in stub-end terminals on the fringes of the central business district (CBD). The lines were often independent of each other, and their coordination and joint fares with regular transit services (bus, streetcar, and rapid transit) seldom existed. The services were heavily commuter-oriented, consisting of a large number of trains serving during the peaks, and minimal service, if any, during off-peak hours. Headways were typically irregular, with various express runs, usually also at irregular intervals. Such networks and services have existed in Boston (North and South stations), Chicago (seven different companies), New York (several systems with stub-end stations--Grand Central and Hoboken--and one through station--Pennsylvania) and Philadelphia (Suburban Station and Reading Terminal). Because of this type of network and service, these railroads were predominantly serving trips into and out of CBDs, most of them to and from work. The percentage of trips made for "other purposes" was quite small, and efforts to attract them were minimal.

In addition to the purely radial network and commuter-oriented schedules, there were organizational problems: private railroads, which were usually not fully compensated for passenger services, were either disinterested or directly opposed (Southern Pacific in San Francisco) to any improvements of their lines. Moreover, the old-time practices and mentality, typical for many of these organizations, resisted most changes.

Regional Rail System Characteristics

In many European and Japanese cities, the interest in and support for local railway services have always remained strong. Through their improvements (mostly since World War II), the concept of regional rail--a modernized version of commuter railroads--has evolved. Regional rail systems are characterized by the following features:

1. Networks consist of electrified diametrical lines through a central city with several stations in it;
2. The utilization of centrally controlled doors, high-platform stations, and several other characteristics similar to those of rapid transit;
3. Convenient transfers (joint stations, coordinated schedules, and integrated fares) with all other transit services; and
4. Clock headways and regular, reliable service throughout the day.

With these characteristics, regional rail systems become integral parts of regional transit; they still have dominant flows during the peak hours, but their role for noncommuting trips increases substantially.

The best example of a conversion from commuter to regional rail system is the S-Bahn in Munich. In 1972, its two stub-end terminals were connected with four stations by a tunnel through the CBD, and regular, electrified services were introduced that were fully integrated with rapid transit, light rail, and bus. Daily ridership on this S-Bahn, which was 150,000 in 1971, had grown to 590,000 by 1982. Similar improvements and ridership increases have been achieved in Frankfurt, Hamburg, Paris, and many Japanese cities.

REGIONAL HIGH-SPEED RAIL SYSTEM IN PHILADELPHIA

It could be said that the era of modern regional rail systems in the United States started with the opening of the Bay Area Rapid Transit (BART) system in Oakland, California. By its network, form, and service, BART is more similar to the S-Bahn in Munich or the Réseau Express Régionale in Paris than to rapid transit systems in Chicago, Philadelphia, and even New York. The Washington, D.C., Metro system will also have a somewhat regional character. However, among the cities with existing commuter railroads, Philadelphia is the first to upgrade its system into a Regional High-Speed Line (RHSL) system.

System Description

The Southeastern Pennsylvania Transportation Authority's (SEPTA) RHSL Network, shown to scale in Figure 1 and schematically in Figure 2, consists of two previously separated networks. The Western (or ex-Pennsylvania) Division consists of 6 lines that converge from the west into the 30th Street station and terminate in the underground Suburban station, west of City Hall. The Northern (or ex-Reading) Division consists of 7 lines converging from the north into the elevated Reading Terminal which is east of City Hall. The entire network has a length of 344 km (214 mi), 189 stations, and a fleet of 343

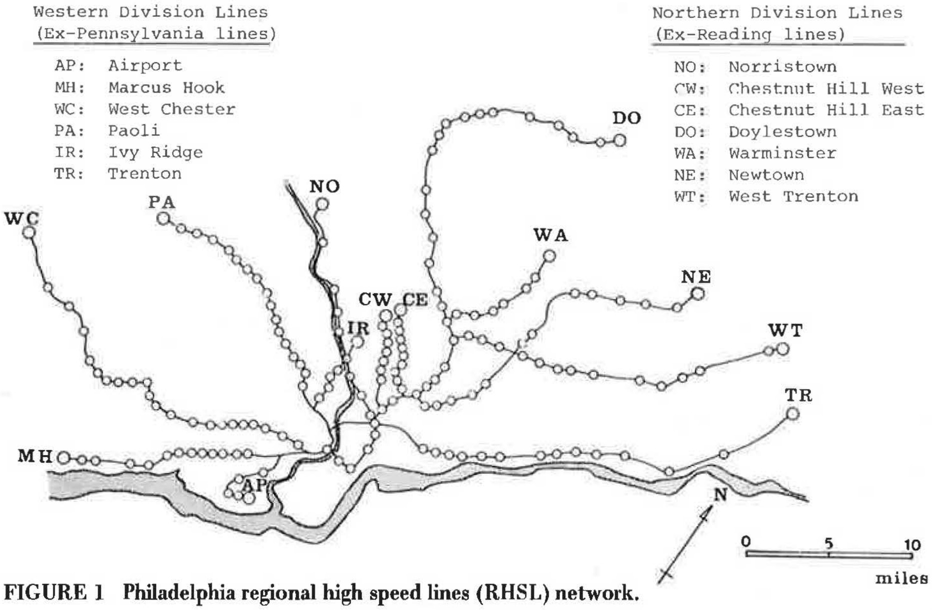


FIGURE 1 Philadelphia regional high speed lines (RHSL) network.

cars, of which 33 were built in 1931, and the others are four, 26-m (85-ft) Silverliner car models built between 1958 and 1975, with 100 to 127 seats each.

Most lines have double tracks; however, some outlying sections have single tracks, while substantial trunk sections have four tracks. Three major lines--Marcus Hook, Paoli, and Trenton--use Amtrak tracks. Headways on most lines are hourly during the day and evening, but 20 to 30 min during peaks. Paoli, Media-Elwyn, and Chestnut Hill West stations have 30-min headways and 10 to 20-min headways with various express runs during peaks.

The decrease in ridership during the 1950s was reversed as a result of some service improvements

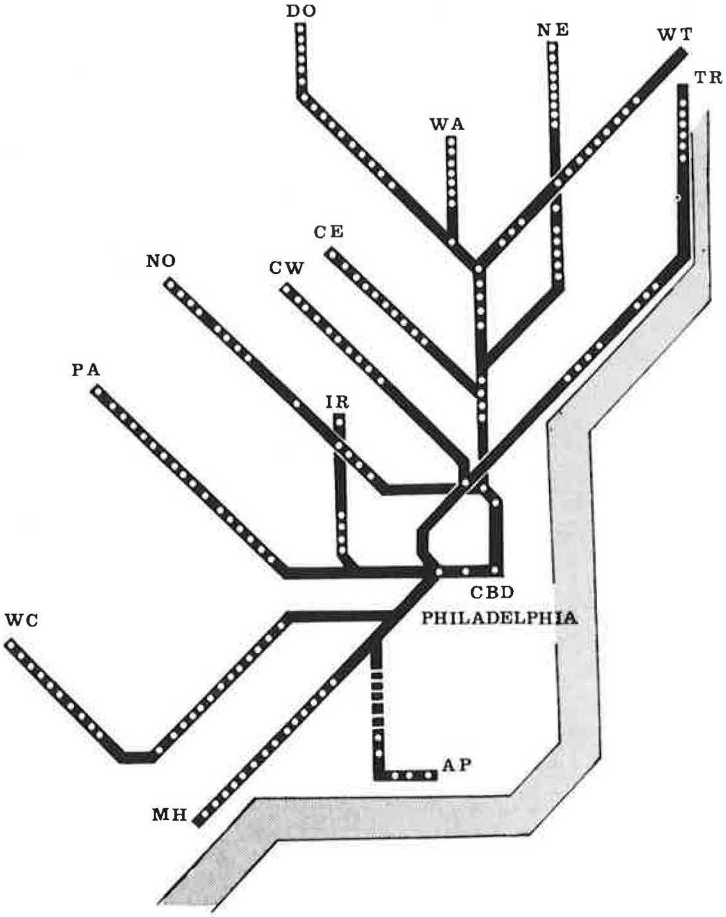


FIGURE 2 Schematic presentation of SEPTA's RHSLs.

around 1960. Between that year and the late 1970s, there was a nearly 50 percent increase in ridership, which reached a peak of 130,000 riders per day in 1979. Sharp fare increases, a drop in reliability of service, and a 105-day strike in 1983 resulted in a precipitous drop in ridership to 55,000 per day, subsequently recovering to 75,000 per day. Passenger volume is extremely peaked, as will be discussed later.

The Tunnel

A 4-track tunnel that will connect the Western and Northern Divisions (see Figure 2), and which has been in the planning stages for approximately 20 years, was completed and opened in fall 1984. The two stub-end terminals have thus been replaced by a 4-track trunk section containing three major Center City stations (30th Street, Suburban, and Market East) and several minor stations in the Northern Division. This section is shown in Figure 3. As can be seen from the figure, there is only one grade-separated junction on the trunk section; all junctions in the Northern Division and most junctions in the Western Division are at grade. This condition imposes constraints on headways and, consequently, on track capacities.

The Airport Line

Another addition to the RHSL network will be the nearly completed Airport line, which will be in the Western Division (the dashed line in Figure 2). The projected ridership for this line is quite low (approximately 2,000-3,000 per day), but its service will be significant for the city and region, as it will provide the only reliable connection between the airport and many points in the region.

BASIC LINE PATTERNS AND PLANNING PROCEDURE

There are several options in organizing the lines and method of operation in a transit network consisting of two "bunches" of radial lines connected by a single trunk section, as has been the case in Philadelphia. Three alternative concepts of lines and their operations should be considered: radial versus diametrical lines; trunk with branches versus trunk with feeders; and fixed operation of trains on individual lines versus changeable train routing among lines. These three sets of alternatives are largely independent from each other and can be combined in different ways (e.g., feeders can be operated with radial or diametrical lines).

Radial Versus Diametrical Lines

In comparing diametrical lines with radial lines (see sections a and c of Figure 4), the following advantages (+) and disadvantages (-) were observed:

+ Better connectivity--passengers from each leg are able to reach more destinations without transfers;

+ Terminals, which require space and maneuvers, are not needed in the usually congested central area of the city;

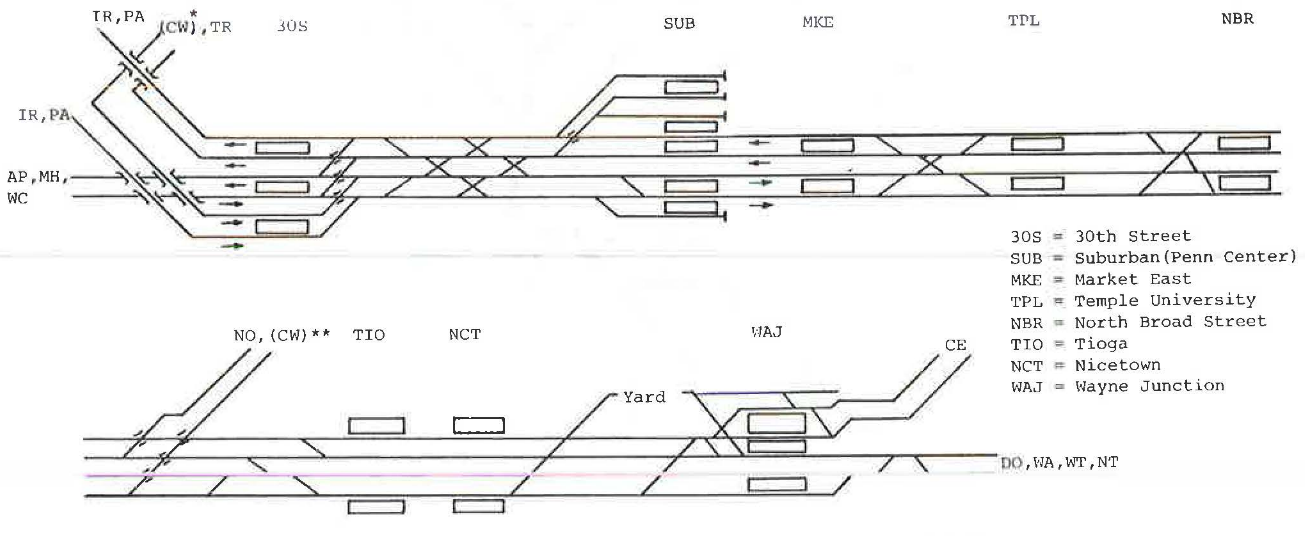
+ Terminal time may become a smaller percentage of cycle time;

- Delays from one leg are transferred to the other, reducing service reliability;

- Critical passenger volume on either leg dictates service requirements for the entire line, often resulting in lower average load factors.

In most cases, the advantages of diametrical lines heavily outweigh their disadvantages compared to radials. For that reason, many transit (streetcar and bus) networks were changed from their initial form of radial lines to a set of diametrical lines.

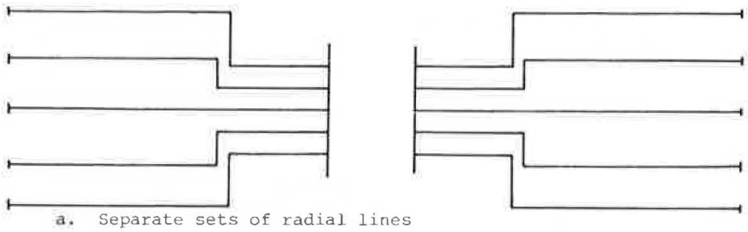
In the case of Philadelphia, the former two separate sets of radial lines looked as shown schematically in Figure 4 (section a). If the lines were to continue to be operated as radials after the tunnel is opened, they would have to overlap on the trunk section (see section b of Figure 4) to realize the advantages of the tunnel. This would create capacity problems. In addition, terminating trains from each network on the opposite side of the CBD would obviously result in many more train-hours and train-kilometers than if the trains are sent out from the trunk to the other division as diametrical lines



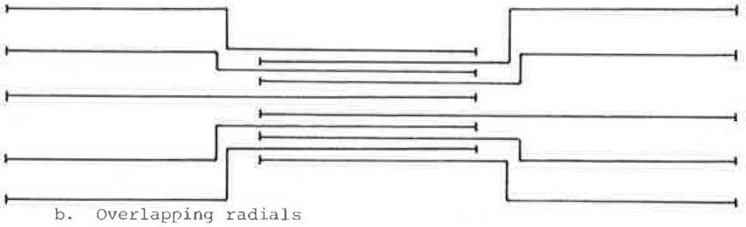
* - Stage 1: Interim Stage, Chestnut Hill West line (CW) is on the Western Division

** - Stage 2: Final Stage, Chestnut Hill West line (CW) is on the Northern Division

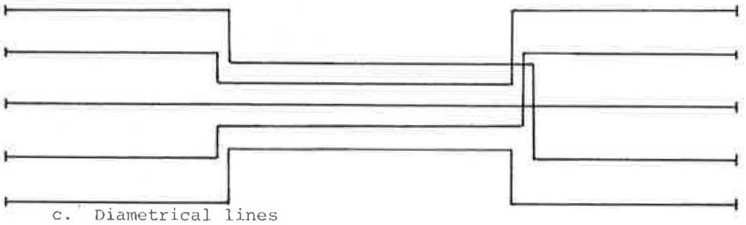
FIGURE 3 Future track layout of the trunk section: 30th Street station to Wayne Junction.



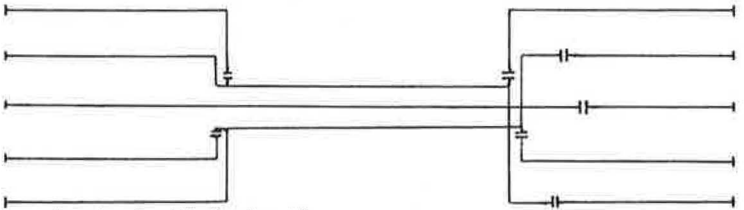
a. Separate sets of radial lines
(Philadelphia before 1984)



b. Overlapping radials



c. Diametrical lines



d. Trunk with feeder lines concept

FIGURE 4 Basic line pattern concepts.

(see section c of Figure 4). This does not prevent the option of terminating, or starting in central city terminals some peak hour trains that are needed in one direction only (inbound in the morning, outbound in the evening). In other words, the lines are operated as diametrical ones, but some peak hour trains can be inserted as extra radials, serving only the peak direction.

Trunk with Branches Versus Trunk with Feeders

Another issue is whether all trains should branch out to different lines and run to their outer ends in the suburbs, or should be terminated at a major station and the outer section operated by a shuttle train as its feeder (see section d of Figure 4).

In comparing branches with feeders (shuttles), the following advantages (+) and disadvantages (-) were observed:

+ No passenger transfers are required;
+ Less terminal time is involved (longer lines);
- There is a lower average load factor because each full-size train runs the entire length of the line, while the capacity of the feeder (shuttle) train can be adjusted to the usually much lower volume than the trunk line carries;
- Delays on the outer sections affect operation on the entire line;
- Scheduling is less flexible--the shuttle can operate with headways two or three times longer or shorter than the trunk.

In most cases, the two advantages of the branch-type operation easily outweigh its disadvantages. In the case of Philadelphia, it was found that feeders are advantageous only in a few cases, such as Elwyn-West Chester, where the outer section has single track and much lower passenger volume than the trunk line (from CBD to Elwyn).

Variable Versus Fixed Train Routings

In operating trains for the three line patterns described previously, two basic train routing patterns--variable routing and fixed train routing--must be evaluated. Fixed train routings compared with variable train routings have the following advantages (+) and disadvantages (-):

+ Simplicity of operation and minimum passenger confusion as to the train destinations;
+ Operating irregularity of schedule disturbance is limited to a single line only;
- Lower fleet utilization may result if the volumes of the two sections of the line pair are not balanced.

The benefits of the variable train routings are far less significant than the advantages of greater simplicity for passengers and operating regularity of service, which the operation of independent lines would bring.

Identity of Lines

An important aspect of transit service is always its image with the public. To have a strong image, the network must be simple, its lines clearly identified. That will be achieved by the operation of fixed lines, regular headways, and clear designations. Because the headways on regional rail lines are typically long (20-60 min), only clock headways should be used. To be recognized, each line should have a clear designation, such as R-1, R-2, and so forth (R will identify "Regional Rail").

Line Pairing Procedure

The analytical procedure developed for line reorganization consists of the following steps:

1. Identification of System Characteristics and Requirements--physical and operational characteristics of the network, constraints, passenger demand, passengers' and operator's requirements are identified.
2. Development of Alternative Sets of Lines--based on the analyses and guidelines developed in Step 1, several alternative sets of lines are developed.
3. Evaluation and Selection of the Optimal Set of Lines--evaluation criteria are developed and used to evaluate alternative sets of lines; the best alternative is then selected.
4. Development of Operating Plans--detailed operating plans are prepared for the best alternative set of lines, including accelerated services, line designations, and schedule coordination with other modes.

A flow chart of this planning procedure is shown in Figure 5. The analysis, evaluations, and plan selection are, naturally, more complicated than the diagram shows and involve many iterative procedures. The previously described steps are discussed in more detail in the following two sections.

LINE PAIRINGS: CONDITIONS AND REQUIREMENTS

In the first step of the planning procedure, all relevant data concerning the RHSL system were collected, analyzed, and systematically presented in a number of charts, diagrams, and tables.

System Characteristics and Constraints

Physical and operational characteristics of the network include the following:

1. Line lengths, stations and their locations, and platform types and sizes;
2. Track layout including alignment, crossovers, signal systems, and their operation;

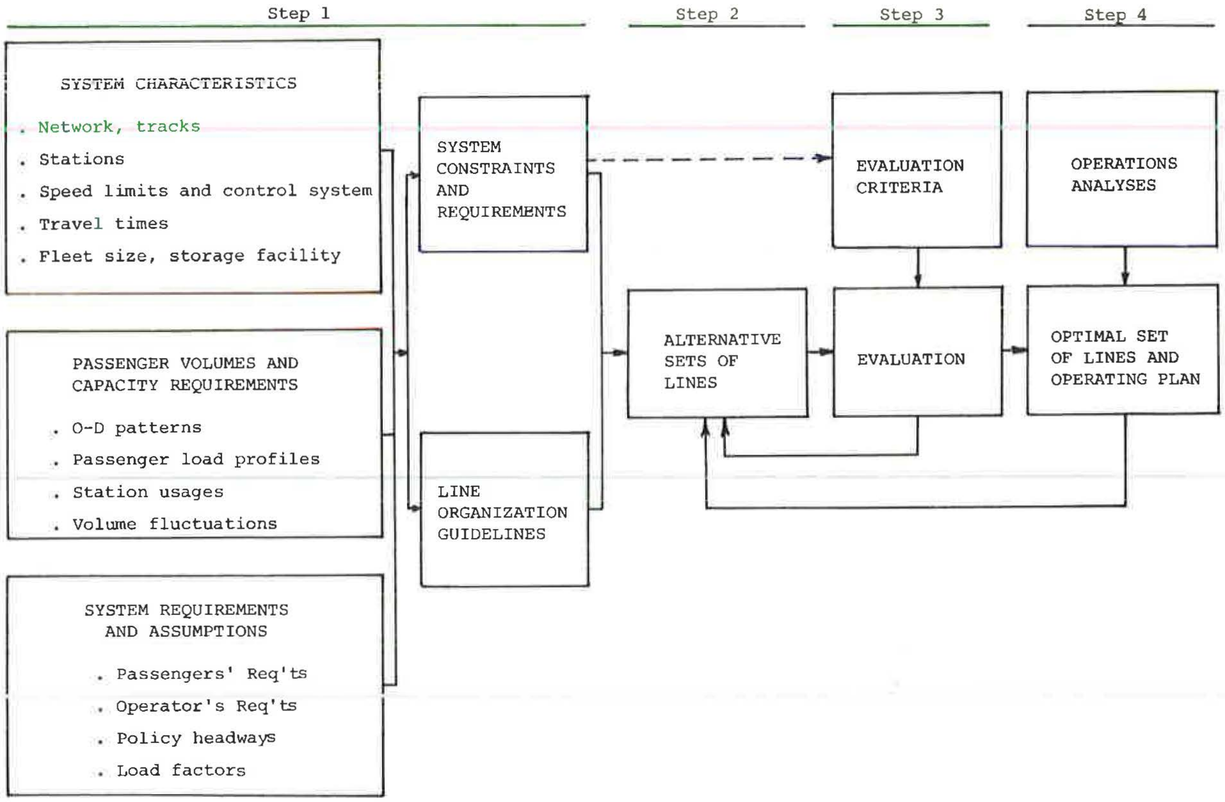


FIGURE 5 Line pairing procedure.

3. Speed limits and travel times;
4. Fleet size and storage facilities (tracks and yards).

These system characteristics determine the range of operational capabilities. One of the most important operational constraints derived is the minimum headway for each line and for each joint section. The elements determining the minimum headway may be the signal system, turnaround time at terminals, or station standing time. During the peak periods, the last factor is often the critical one. Platform lengths along each line control the maximum train consist that can be operated. The minimum headways and maximum train consist determine the capacity of each line.

Another important consideration is the pattern of track paths through the trunk section of the network. Different line pairings must be analyzed with respect to the mutual crossings (or weavings) of their train paths, to find the pairings that are the least conflicting operationally. The analysis of headways on the Philadelphia RHSL system resulted in the desirable minimum headway of 4 min on each track of the trunk section. With respect to track paths, the best combinations of line pair track assignments were identified.

Passenger Volumes and Capacity Requirements

Because both capacity and level-of-service requirements depend largely on passenger volumes, a detailed demand analysis must be performed. This analysis should include: (a) system-wide demand and its breakdown on individual lines, (b) time variations (including peaking patterns), and (c) passenger demand by station and volume profiles of lines by direction and time period. (Examples of these are shown in Figures 6 and 7, respectively.)

From these data, the maximum load section (MLS) is determined for each line. Combined with adopted load factors, which may vary among lines and time periods, capacity requirements are derived for each line segment and for each scheduling period of the day. For the SEPTA RHSL system, the policy decision was made based on past experiences, recent trends, and plans for service improvements to design for a total daily ridership of 100,000. The distribution of this volume on individual lines was based on

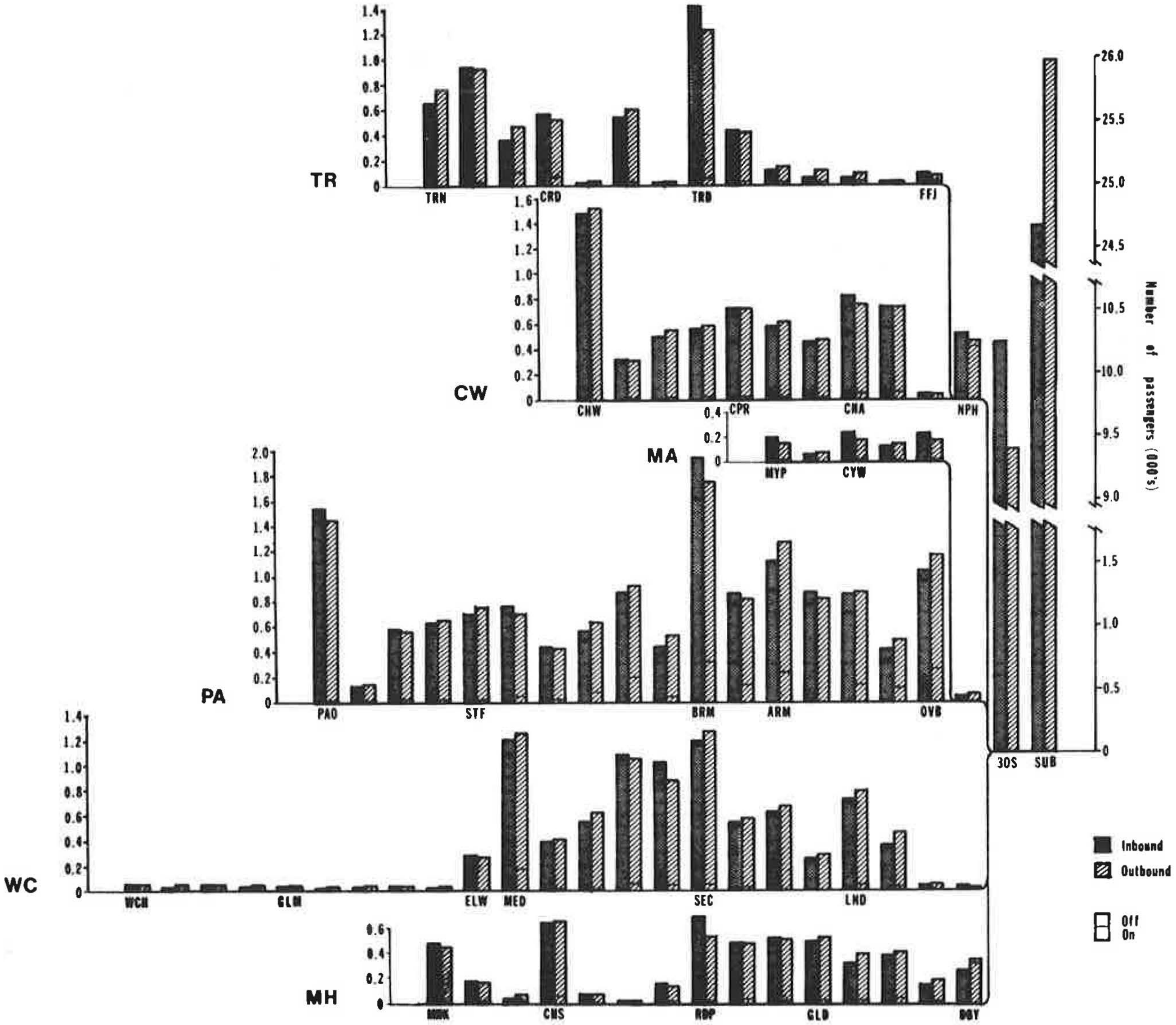


FIGURE 6 Daily station usage—ex-Pennsylvania lines (boarding and alighting).

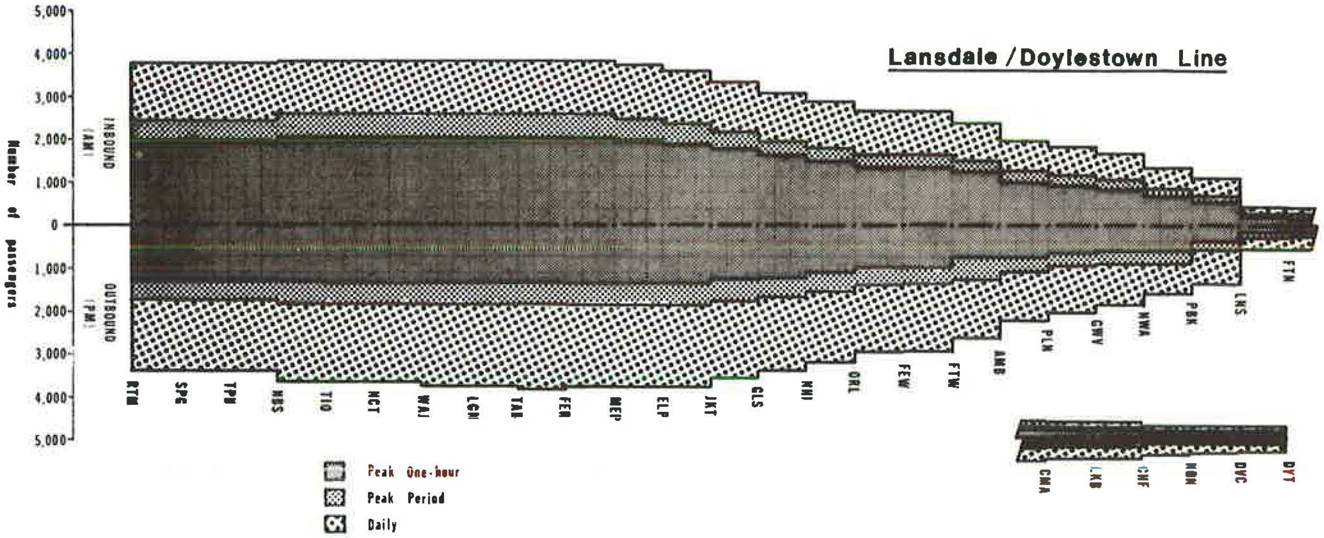


FIGURE 7 Future passenger volume profile by direction for different periods.

historical records of proportions among the lines, corrected by the trends during the recent years.

An interesting detail in the analyses of passenger volumes was a plot of fluctuations of arrivals and departures at the CBD terminals. One of these plots (see Figure 8) shows the extremely sharp peaks that create problems in pairing the lines--the heavy inbound passenger volume far outweighs the light outbound volume, resulting in low load factors on the nonpeak directions.

The required capacities in terms of cars per hour were computed by dividing the passenger volumes on each MLS by the adopted load factors (which ranged from 0.65 to 0.95), and by car capacity (120 seats). The obtained numbers of cars per hour per direction were then translated into different combinations of frequencies (headways) and train consists.

Other System Requirements and Assumptions

A number of other considerations were included in the process of analysis for line pairings. The passenger preference for reliable, convenient, and simple service is largely satisfied by the fixed lines and clock headways discussed previously. The operating agency is also concerned with passenger attraction, as well as with operating efficiency and minimum costs. These factors, together with local characteristics, were continuously considered in preparing alternative line pairs.

LINE PAIRINGS: DEVELOPMENT AND SELECTION

Having identified physical and operational characteristics of the system, passenger demand, con-

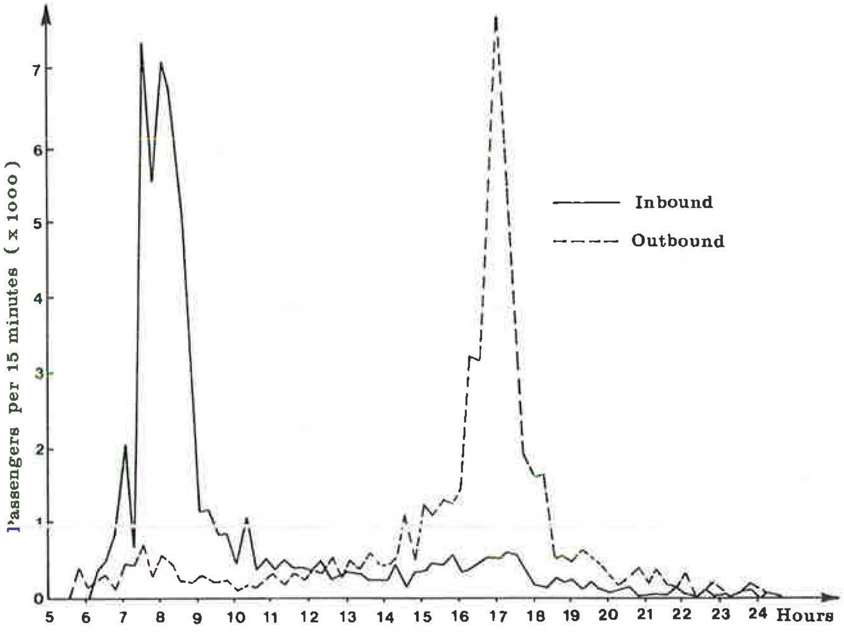


FIGURE 8 Fluctuations of 15-min passenger volumes on all RHSLs in 1979.

straints, and system requirements, and considering various aspects of radial, diametrical, and trunk-feeder line configurations described previously, several alternative sets of lines were developed.

Method of Line Pairing

The guidelines formulated for determining line pairs between the two networks are as follows:

1. Connect lines with high through-travel potential; because there are usually no past data on this travel (because such trips could not be made), the estimates must be made that consider (a) the distribution of employment and residential areas by type and volume and (b) geometric forms that are attractive for through trips (avoiding "loop" or "U"-shaped lines).
2. Connect lines with similar passenger volumes and off-peak policy headways--define the volume in cars per hour in the peak periods, peak directions, and policy headways in off-peak periods for the two sets of lines and then try to match them when forming the pairs. This is usually the most important single guideline, because it has the most direct impact on fleet utilization (i.e., achievement of balanced load factors).
3. Select pairs with minimum track path conflicts. This applies only to the cases when the trunk section has more than one track per direction. The sets of pairs that can be routed over two parallel tracks without crossing their paths are more advantageous than the line pairs that would criss-cross their paths, causing capacity constraints. Thus good selection of pairs minimizes conflicts, resulting in greater capacity, reliability, and safety.
4. Balance total frequencies on the two pairs of trunk line tracks.
5. Avoid pairing two lines that have single track sections to lessen headway limitations, propagation of delays, and so forth.
6. Avoid excessively long cycle times (crew rest and reserve time for schedule recovery also increase with longer cycle time), and, as much as possible, try to make them close to integer multiples of headways (particularly when these are long) to avoid excessive time losses at terminals.

In the case of SEPTA's RHSL, these guidelines were followed as much as the specific conditions allowed. Meeting future demand for travel through the CBD was not an important factor (except for the Airport line) because transferring among lines would be easy--the geometry of existing lines made the formation of two loop lines unavoidable.

Matching passenger volumes and policy headways was the most important single factor in determining pairs. For this purpose, the former two sets of radial lines were listed in two columns in descending order of peak hour passenger volume, as shown in Figure 9. To satisfy the second guideline, connections between radials should be as close to horizontal lines as possible. Alternatively, a heavily loaded line on one side could be split into two radials on the other side (e.g., Paoli-Bryn Mawr to Doylestown and Fox Chase).

A detailed analysis of track path conflicts was made and desirable line pairs with respect to this factor were defined. At the same time, efforts were made to achieve a balanced utilization of all four tracks on the trunk section. Furthermore, the pairing of two radials with single track sections was nearly completely avoided. Finally, a matrix of cycle times for all permutations of line pairs was developed to analyze them with respect to the requirements of the sixth guideline. The depth of this analysis was limited by the difficulties of establishing operating times on individual lines because of various and varying speed restrictions, requirements for terminal times, and so forth. Theoretically, there could be 720 different sets of lines. The guidelines greatly helped to formulate the sets that have the most favorable diametrical lines and that avoid potential problems that the guidelines warn against. Approximately a dozen line set alternatives were initially developed.

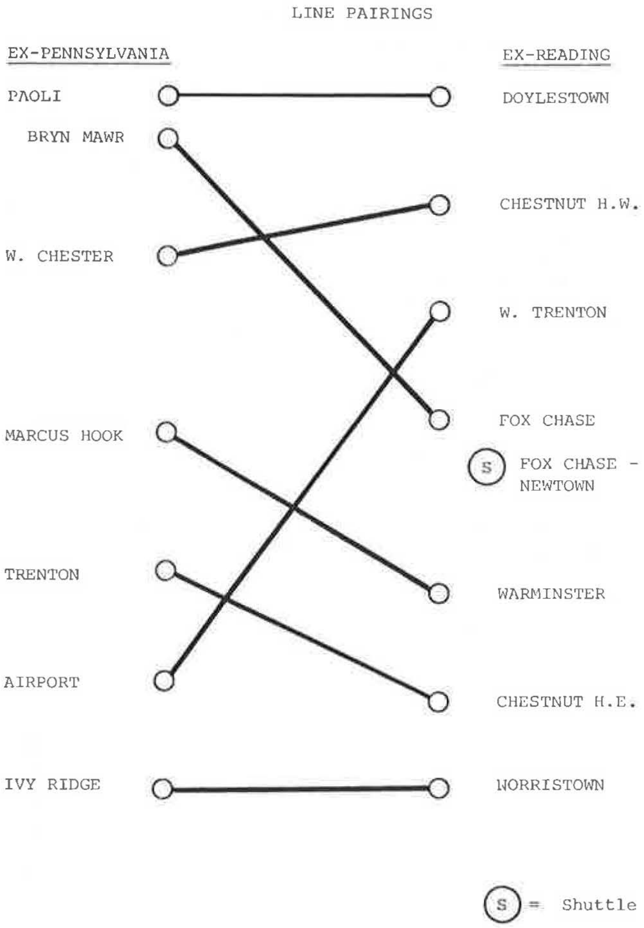


FIGURE 9 Recommended pairings.

Evaluation and Selection of the Optimal Line Set

The criteria for evaluation of line sets are based on system requirements and pairing guidelines. They include quantitative and qualitative items, the major ones being:

- Fleet size requirement
- Train frequencies on all trunk line tracks and their balance
- Headways on individual lines
- Car- and train-miles, car- and train-hours
- Platform lengths and train consists
- Possibilities of implementing accelerated services
- Crew requirements
- Other factors that influence operating costs
- Various operational aspects (reliability, capacity, conflicts, etc.)

In the SEPTA RHSL study, the initially formulated sets were reviewed and those obviously inferior to others were eliminated or modified (2). This preselection resulted in a total of three alternatives with the following dominant features: (a) as many diametrical lines as possible; (b) maximum trunk-feeder line combinations; and (c) combination of diametrical lines with a few radials for peak hours and feeders on single-track sections. These three alternatives were then evaluated with respect to all major operating and service indicators. Train travel times were computed for some lines by a train simulation model. Based on this evaluation, the third alternative was selected as the best. The lines of this alternative, recommended for implementation, are shown with their designations in Figure 10.

Development of Operating Plan

For the selected set of lines, detailed operating plans must be prepared that include: headways and train consists, line designations, accelerated service possibilities, train routings during the transitions between peak and off-peak periods, passenger information, and other operational details (such as train numbering, crew scheduling, etc.). In addition, an implementation plan for facilitating the transition to the integrated network must be developed.

For the SEPTA RHSL study, headways and train consists were prepared for each schedule period and for each direction, by carefully examining passenger capacity requirements, minimum headways, and platform lengths on the legs of of each pair. Table 1 gives a summary of the operational data of each line pair including line length, travel time, cycle time, headway, and train consist during the off-peak period, while Figure 11 shows off-peak headways on a schematic line diagram. The lines have been systematically designated by a number following the letter "R". The line numbers increase clockwise for the Western Division line from the Airport--West Trenton line (R-1) to the Trenton--Chestnut Hill East line (R-7), as shown in Figure 10.

The accelerated service (zonal, express-local, and skip-stop) possibilities were also investigated for three heavy-volume sections: Media-CBD, Paoli-CBD, and Jenkintown-CBD. Because one of the most important operating features of regional rail is the maintenance of fixed headways, accelerated service runs were considered as additions to the regular fixed schedule runs, thus not replacing the basic uniform headway pattern.

The train routings during the transition between peak and off-peak, and vice versa, were examined to

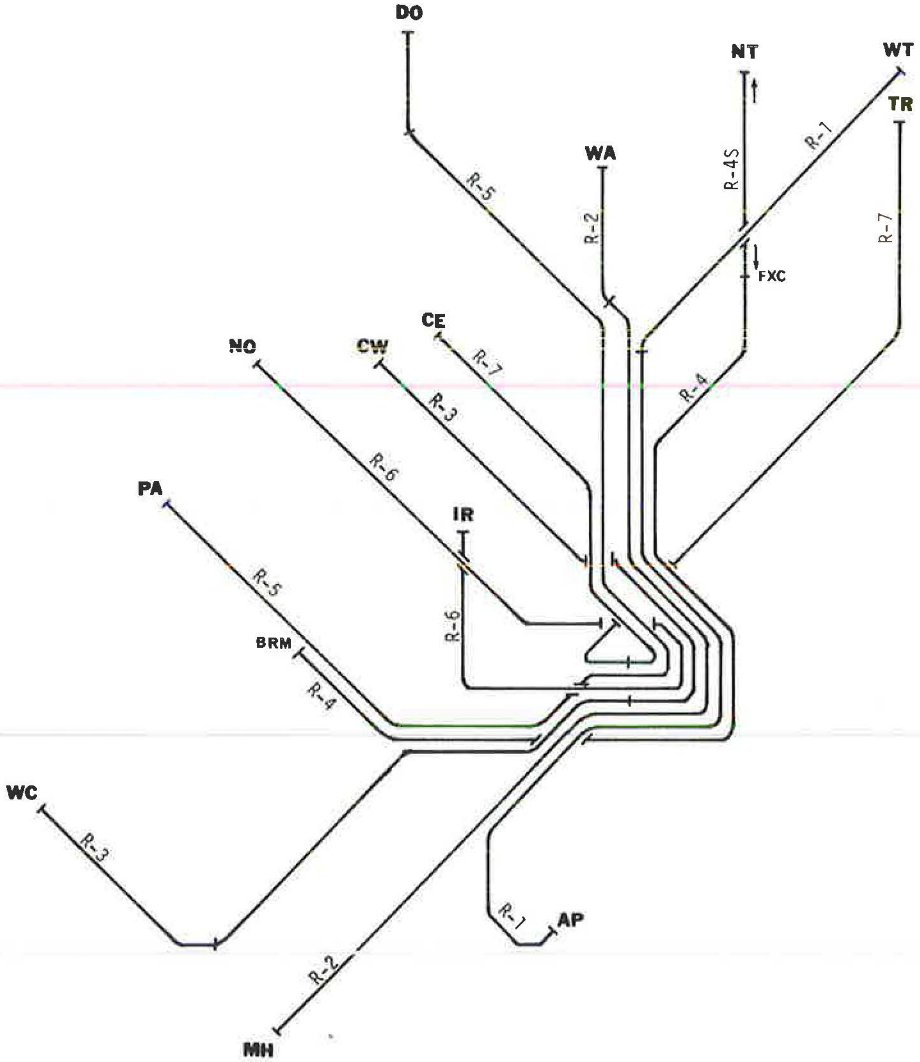


FIGURE 10 Schematic of the recommended lines—stage 2.

TABLE 1 Recommended Lines and Their Operating Data—Off-Peak

					Stage 1[b]			Stage 2[c]			
Designation	Line	Length (mi)	One-Way Travel Time (min)	Cycle Time[a] (min)	Headway (min)	Frequency (trains/hr)	Train Consist (cars/train)	Headway (min)	Frequency (trains/hr)	Train Consist (cars/train)	Comments
R-1	AIR-WTR	42.9	87	204	60	1	1	60	1	1	
R-1	AIR-JKT	21.2	47	124	20/40	2	1	20/40	2	1	
R-2	MHK-WMR	37.7	90	210	60	1	2	60	1	2	
R-2	MHK-GLN	29.5	73	176	–	–	–	–	–	–	Peak hour only
R-3	ELW-CHW	26.6	67	164	–	–	–	30/60	4/3	1	Total service ELW-WAJ: headway = 30 min
R-3	ELW-WAJ	21.2	52	134	30/60	4/3	1	–	–	–	
R-3	WCH-CHW	38.9	92	214	–	–	–	90	2/3	1	
R-3	WCH-WAJ	33.5	77	184	90	2/3	1	–	–	–	
R-4	BRM-FXC	22.2	58	146	–	–	–	30	2	1	Total service BRM-WAJ: headway = 15 min
R-4	BRM-WAJ	16.3	40	110	30	2	1	–	–	–	
R-4(S)	FXC-NWT	15.2	34	98	–	–	–	90	2/3	1	
R-5	PAO-DYT	55.3	105	240	60	1	1	60	1	1	
R-5	PAO-LNS	45.3	87	204	60	1	2	60	1	2	
R-6	IVR-NTE	27.5	69	168	60	1	1	60	1	1	
R-7	TRN-CHE	44.7	89	208	60	1	1	60	1	1	
R-7	TRN-WAJ	39.0	71	172	–	–	–	–	–	–	Peak hour only
R-8	CHW-FXC	23.4	64	158	30	2	1	–	–	–	

[a] Terminal times = 15 min, SUB-MKE = 4 min one-way, and MKE-WAJ = 10 min one-way.
[b] For Stage 1 (the interim stage), the Chestnut Hill West line is on the Western Division.
[c] For Stage 2 (the final stage), the Chestnut Hill West line is on the Northern Division.

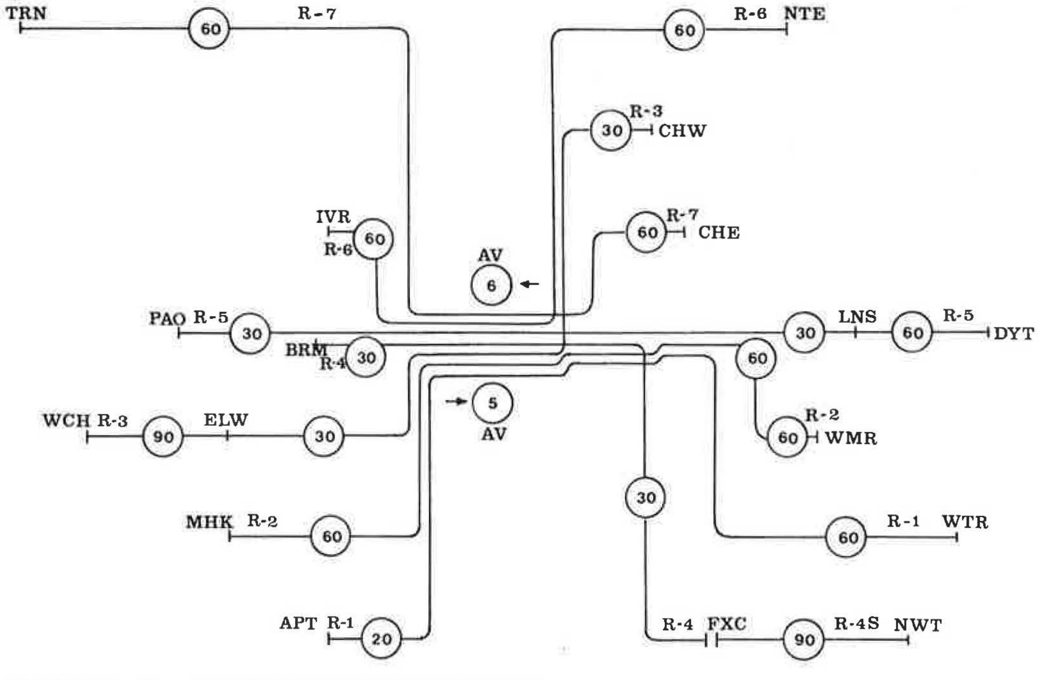


FIGURE 11 Recommended lines and off-peak headways.

minimize deadhead kilometers and operational complications. The SEPTA RHSL has two major car storage yards at both sides of the tunnel: Powelton Yard (capacity 152 cars), near 30th Street station on the Western Division, and Wayne Junction Yard (capacity 100 cars) on the Northern Division. At the end of a peak period, most excess peak trains from the Northern Division travel to Powelton Yard for storage, and, likewise, most excess trains from the Western Division travel to Wayne Junction Yard. At the end of an off-peak period, the reverse of the above movements was planned.

Other operational details and implementation plans such as the staged introduction of the Airport line and switching of the Chestnut Hill West line from a Western Division line to a Northern Division line were also prepared.

COMPLEMENTARY ACTIONS

To achieve a modern, efficient, and integrated regional rail system, the physical connection of lines must be complemented by a number of improvements in scheduling, operation, and service for present and potential passengers. A short review of the most important needed improvements and changes in operating practices follows:

1. Schedules--should have built-in reserves of 1-2 min at locations where heavy passenger loads, line merging, or other factors may cause variations in travel times, in order to ensure greater schedule reliability.
2. Basic schedules--must be regular, with constant headways (or their multiples). Zonal and ex-

press services should be provided in addition to regular local train runs, rather than replacing them, creating irregular services at many stations.

3. Station dwell times--at all busy stations must be shortened through improved boarding-alighting procedures and dispatching practices. The leisurely-type of operations prevailing today must be replaced by a faster process, similar to rapid transit operation.

4. Reliability of service--should be given top priority. In addition to the necessary changes in scheduling and station operations, procedures for handling delays must be improved and personnel trained accordingly.

5. Physical improvements--have been accelerated in recent years, must be continued; badly deteriorated systems must be brought up to higher standards if high-quality service is to be provided.

6. Modern fare collection methods--should eventually replace the present manual handling of all fares and tickets.

7. Rolling stock--should be analyzed for possible modifications needed to improve operations. A major study should precede any future order of vehicles to ensure that future cars will (a) meet the needs of the new type of operations and (b) provide conditions for maximum efficiency. This should include such items as the number and control of doors, communication systems, and public information needs. The possibility of further crew reductions, which would allow higher frequency of shorter trains, is a particularly important item.

8. Coordination of capital improvements with the planned operating practices is of utmost importance. Because of the numerous fundamental changes in the operations and organization of the RHSL in Philadelphia without adequate time for planning, present improvements of tracks, station platforms, fare collections, and so forth, are being made without full mutual coordination. A study should be made to plan for full compatibility of these (and many forthcoming) improvements and thus ensure maximum effectiveness of the investments in the Philadelphia PHSL.

ACKNOWLEDGMENT

The study reported in this paper was undertaken by a team of researchers under the direction of the authors at the University of Pennsylvania and the University of Delaware. The study was financed by and performed for the Southeastern Pennsylvania Transportation Authority (SEPTA). The sponsorship and cooperation by SEPTA's personnel are gratefully acknowledged.

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TrailPass User Survey for the Philadelphia Regional Commuter Rail Lines

THABET ZAKARIA, W. THOMAS WALKER, and P. TAKIS SALPEAS

ABSTRACT

This paper contains a description of the development and findings of a survey conducted among the users of a prepaid discount transit fare program known as the TrailPass. This program enables the holder of the TrailPass to make an unlimited number of trips on any commuter rail, rapid transit, bus, streetcar, or trolley line in the Philadelphia regional transit system, which is operated by the Southeastern Pennsylvania Transportation Authority. The survey was conducted in May 1984 by the Delaware Valley Regional Planning Commission as part of its regular work program for providing technical assistance to the transit operators. The survey results, which are based on a 16-percent sample, indicate that the TrailPass program can be beneficial to both transit operators and passengers. The TrailPass increases mobility and makes transit affordable, convenient, and attractive for the riding public because it allows the user to save time and money as well as make more trips. The increase in TrailPass sales reduces the cost of collecting and managing cash fares for the transit operator. Prepaid transit fare programs similar to the TrailPass could be implemented successfully in any metropolitan area with multimodal transit systems.

The Philadelphia regional high speed lines (commuter rail lines) form a key element in the total transportation system in the Delaware Valley Region. Thirteen lines connect Center City Philadelphia with other parts of the city and with the four suburban counties of Bucks, Chester, Delaware, and Montgomery. Approximately 37,000 commuters use the rail lines on an average weekday (1). Approximately 20 percent (7,100) of the daily commuters ride the commuter rail system using TrailPasses. The monthly TrailPass is valid for unlimited rail travel (peak and off-peak trains) between Center City Philadelphia and one of the other five fare zones for which the TrailPass is purchased. In addition, the TrailPass is good for unlimited transit rides in the City of Philadelphia and adjacent suburban transit fare zones, up to the zone shown on the face of the TrailPass. For example, a Zone 2 TrailPass is valid within the City of Philadelphia transit fare zones 1 and 2 and suburban transit fare zones 1 and 2 (which are adjacent to the city) as well as within fare zones 1 and 2 of the commuter rail system.

The price of the monthly TrailPass to individuals at the time of the survey ranged from $45,000 for the Terminal Zone to $115.00 for fare zone 5. Employees of companies involved in the Southeastern Pennsylvania Transportation Authority (SEPTA) Corporate Pass Program, known as COMPASS, can obtain TrailPasses through a 10-percent discount payroll deduction plan (2).

In May 1984, the Delaware Valley Regional Planning Commission (DVRPC) conducted a survey among the users of the SEPTA TrailPass program to obtain information that would assist SEPTA in (a) developing marketing and promotional programs for the high speed lines and (b) assessing their pricing policies. The purpose of this paper is to describe the TrailPass survey, summarize its results, and highlight the major findings. The results of the survey may be useful to other transit operators in establishing and administering prepaid transit Pass programs that reduce the cost of fare collection and make transit more affordable and convenient for the riding public.

DESIGN OF THE SURVEY QUESTIONNAIRE

The survey questionnaire, shown with survey findings in Figure 1, was designed by DVRPC in cooperation with SEPTA. The questionnaire surveyed TrailPass buyers on three general issues: (a) characteristics and frequency of TrailPass use, (b) attitudes and perceptions, and (c) demographic and socioeconomic characteristics. The questionnaire was made as simple as possible so as to be self-explanatory.

Frequency and Characteristics of TrailPass Use

Past experience from similar surveys indicated that some respondents would have difficulty in correctly specifying the number of trips made using the TrailPass (3). Therefore, an assessment of weekly trips made by the TrailPass users was obtained via two independent questions. Question 5 asked for the number of days per week that the TrailPass was used, and Question 6 asked directly for how many times per week the TrailPass was used on the regional high speed lines for all travel purposes. For example, if a respondent used the Pass five days a week, the answer to Question 6 must have included at least 10 weekly uses.

Question 7a asked for the number of weekly trips made on the SEPTA City Transit Division and Question 7b was included to determine which City Transit Division routes were regularly ridden by TrailPass users when they transferred from the regional high speed lines to transit routes and when they made supplemental trips. Question 7c asked for the purpose of the trips made on the transit system using the TrailPass. (The response to this question defines the type of these transit trips and determines whether they are made to complete the journey-to-work trips, or whether they included new trips that might not have been made if the TrailPass had not been available.) Question 1 was included to measure the frequency of TrailPass purchase. In this question,

(Numbers in boxes are the answers in %.)

1. How often do you buy the TrailPass? $\boxed{78}$ Every Month $\boxed{19}$ Most Months $\boxed{3}$ A Few Times Per Year

2. Why do you use the TrailPass? $\boxed{20}$ Saves time $\boxed{38}$ Saves money $\boxed{26}$ Convenient $\boxed{14}$ No Need For Having Cash $\boxed{2}$ Other (Specify)_____________________

3. How much do you pay for your TrailPass? $____________

4. How much do you think you save monthly by using the TrailPass? $\boxed{9}$ Less than \$5.00 $\boxed{47}$ \$ 5.00 - \$15.00 $\boxed{23}$ \$15.01 - \$25.00 $\boxed{9}$ \$25.01 \$35.00 $\boxed{7}$ \$35.01 - \$50.00 $\boxed{4}$ More than \$50.00

5. How many days per week do you use your TrailPass? $\boxed{3}$ 4 or less $\boxed{84}$ 5 days $\boxed{10}$ 6 days $\boxed{3}$ 7 days

6. How many times per week do you use your TrailPass for riding SEPTA's commuter rail trains? $\boxed{3}$ 8 or less $\boxed{74}$ 9 - 10 $\boxed{15}$ 11 - 13 $\boxed{5}$ 14 - 16 $\boxed{4}$ 17 - 24 $\boxed{1}$ 25 or more

7. Do you use your TrailPass to ride SEPTA's Subway-El, Trolley or bus routes? $\boxed{76}$ Yes $\boxed{24}$ No

   a. If yes, how many times per week do you use transit routes? $\boxed{61}$ 8 or less $\boxed{25}$ 9 - 10 $\boxed{7}$ 11 - 13 $\boxed{4}$ 14 - 16 $\boxed{3}$ 17 - 24 $\boxed{1}$ 25 or more

   b. If yes, what SEPTA route(s) do use? $\boxed{37}$ Bus or Trolley $\boxed{37}$ Market-Frankford $\boxed{15}$ Broad St. Subway $\boxed{11}$ Subway Surface Lines

   c. If yes, what is the purpose of your trip(s)? $\boxed{43}$ Go to Work or School $\boxed{26}$ Shopping, Lunch, etc. $\boxed{20}$ Midday Work Activities $\boxed{10}$ Go Home from Rail Station

8. What do you recommend for increasing the sale of TrailPasses?

   $\boxed{38}$ Price Adjust. $\boxed{5}$ More Sales Locations $\boxed{10}$ More Advertise. $\boxed{7}$ Use of Credit Cards $\boxed{19}$ Parking Privileges $\boxed{14}$ Weekly TrailPass $\boxed{7}$ Other (Specify)____________________

9. If TrailPasses were discontinued, would you $\boxed{2}$ Purchase Daily Tickets? $\boxed{56}$ Purchase 10-Trip Tickets?

   $\boxed{8}$ Use Other Transit Routes? $\boxed{12}$ Drive Alone? $\boxed{18}$ Carpool Vanpool? $\boxed{3}$ Use Others (Specify)______________

10. Sex: $\boxed{51}$ Male $\boxed{49}$ Female

11. Age: $\boxed{1}$ Under 18 $\boxed{45}$ 18-34 $\boxed{24}$ 35-44 $\boxed{17}$ 45-54 $\boxed{13}$ 55-64 $\boxed{1}$ 65 or over

12. Annual household income: $\boxed{11}$ Under \$15,000 $\boxed{26}$ \$15,000 to \$24,999 $\boxed{21}$ \$25,000 to \$34,999 $\boxed{21}$ \$35,000 \$49,999 $\boxed{21}$ \$50,000 or more

13. Where do you live? $\boxed{11}$ Bucks County $\boxed{9}$ Chester County $\boxed{18}$ Delaware County $\boxed{28}$ Montgomery County $\boxed{31}$ Philadelphia $\boxed{3}$ Other (Specify)____________________

FIGURE 1 TrailPass survey results in percent.

the respondent was to indicate whether he or she purchased the TrailPass every month, most months, or only a few times per year. The third question asked for the price of the TrailPass purchased so that the characteristics of users could be identified by fare zone.

Attitudes and Perceptions of TrailPass Users

Questions 2, 4, 8, and 9 were designed to measure the attitudes and perceptions of TrailPass buyers concerning the TrailPass. The second question solicited the purchaser's reasons for buying the TrailPass. Four specific responses were given relating to time, money savings, and convenience. Because SEPTA desired to decrease costs by reducing the amount of cash fare payment, this aspect of operation was listed separately. Additional space on the questionnaire was also provided in which respondents were asked to indicate any other reasons they may have had for buying the TrailPass.

Question 4 requested the respondent to indicate the amount of money he or she saved monthly by using the TrailPass. This question was included to measure the perceived savings of TrailPass users. The perceived savings could be compared with actual savings computed from the frequency of TrailPass use, including the number of trips made on the transit system, collected in the other sections of the questionnaire.

Question 8 asked for any recommendations that the survey respondent may have had concerning increasing the sale and use of the TrailPasses. The response to this question should give guidance to SEPTA for marketing of the TrailPasses. Six predefined options were given relating to price, sales locations, advertisements, use of credit cards, weekly TrailPasses, and parking privileges. In addition, space is provided for the respondent to recommend other ideas that may increase TrailPass sales.

Question 9 was intended to determine whether TrailPass users would continue to use the regional high speed lines without the TrailPass program. It identifies travel options that TrailPass buyers might have if TrailPasses were discontinued. Responses to the categories "Purchase daily tickets" and "Purchase 10-trip tickets" indicate continued use of the regional high speed lines. Three other travel options are also specified, including the switch from the railroad to the automobile or to the transit system.

Demographic and Socioeconomic Characteristics of TrailPass Users

Questions 10 through 13 were designed to identify the railroad passenger's demographic and socioeconomic characteristics, including sex, age, annual household income, and place of residence. These standardized questions are usually included in DVRPC transit surveys to build a data base for planning purposes and cross-classification of the survey results (3,4,6). This information is also useful for TrailPass marketing research and for identifying population groups that benefit from the TrailPass program.

SAMPLE SIZE

The response to each entry in the questionnaire is a binomial random variable. Assuming that the error distribution of this variable is normal, the sampling error is related to the sample size as follows (6):

$$h = \left\{[(1.96)^2/n]\ p \cdot q\right\}^{1/2} \quad (1)$$

where

h = error of sampling expressed in percent variation from the real or true value of the population,
Z = confidence coefficient (Z) that corresponds to the 95 percent level of confidence in the estimation of the total proportion (P),
p = probability of the event's taking place (the percent response to a survey question),
q = 1-p, and
n = sample size.

The estimation of the sample size (n) for a specified confidence interval (z) and a tolerable error (h) depends on the values of p and q. To ensure that the sample size will be large enough to deliver the precision desired, the most conservative estimate for n is made by assuming p = q = 50 percent. For the purposes of this survey, the tolerable error was specified to be ±3 percent at a confidence level of 95 percent (1.96 from the standard normal probability table). By substituting these values into the formula with p = q = 0.50, the required sample size (n) is 1,067.

To estimate the total number of survey forms for distribution, two additional factors were considered (a) not everyone who receives the questionnaire returns it. From previous experience with similar surveys, it is appropriate to assume that only 35 percent of the questionnaires would be returned for processing; and (b) a portion of the returned questionnaires will be unusable because of incomplete, unreadable, or spurious responses. It is reasonable to consider that approximately 3 percent of the returned survey forms will be unusable for processing. Hence, the total number of survey forms that must be distributed to obtain the required sample size is 3,138 or about 45 percent of all TrailPass buyers in the region.

QUESTIONNAIRE DISTRIBUTION

Twenty-two sales outlets, in which almost 70 percent of all TrailPasses are sold, were selected for distributing the questionnaires. These outlets were scrutinized for representativeness in terms of sales volume, fare zone, and geographic location. These selected outlets are clustered in four major corridors extending southwest, west, north, and northeast from the Philadelphia Central Business District (CBD). Sample sizes ranged from 50 to 100 percent depending on the volume of TrailPass sales. If the volume of sales at a selected outlet was less than 80, then the total number of questionnaires for distribution was equal to the sales volume. Distribution of the TrailPass survey forms at the selected sales outlets was carried out by an agency called Blue Ribbon Services. This agency, under a contract with SEPTA, sells tickets to the users of the Regional High Speed Lines. A package containing the appropriate number of survey forms for each sales outlet was accompanied by a survey instruction sheet indicating that distribution was to be continued on a first-come, first-served basis until all survey forms had been dispensed.

SURVEY RESULTS

Of the 3,138 survey cards distributed, 1,201 (38 percent) were returned. The returned questionnaires were carefully reviewed and responses that were incomplete, biased, or unreadable were discarded before keypunching of the data for computer entry. In all, 1,161 survey forms were processed, representing approximately 16 percent of the total TrailPass sales volume. The number of the processed questionnaires was slightly higher than the required sample size (1,161 versus 1,067) and thus an adequate sample was obtained.

The following paragraphs contain a brief description of the survey findings that are shown in Figure 1. The answers to the survey questions were tabulated by a computer program developed previously by DVRPC for processing responses to similar surveys.

TrailPass Purchasing

The responses to the first question of the survey questionnaire indicated that 78 percent of the TrailPass buyers purchase their Passes every month. An additional 19 percent purchase their Passes most months. TrailPass purchasing consistency increases as the number of days of Pass usage increases. For example, 93 percent of the 7 days-a-week Pass users buy the TrailPass regularly compared to 76 percent of the 5-days-a-week Pass users. This high consistency of TrailPass purchasing reflects the customer's satisfaction with the program.

It should be noted that the Pass holders from the lower income groups are more consistent buyers than those from the higher income groups. Approximately 85 percent of the buyers with household incomes less than $25,000 purchase the Pass regularly while 72 percent with incomes above $35,000 are regular Pass buyers. Female Pass buyers are somewhat more consistent in purchasing the TrailPass regularly than men (78 percent versus 73 percent).

Pass buyers from Philadelphia are more consistent in buying the TrailPass than buyers from the suburbs. Eighty-two percent of the TrailPass buyers from Philadelphia buy the Pass regularly, while on the average, only 75 percent of the buyers from the four suburban counties are regular Pass Buyers.

Reasons for Using the TrailPass

As is shown in Figure 2, 38 percent of buyers cited money-savings as a reason for using the TrailPass.

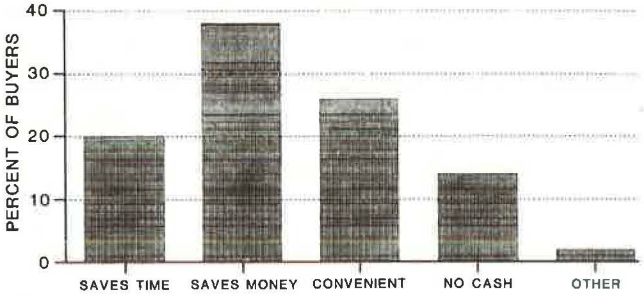

FIGURE 2 Percent of TrailPass buyers by reason for purchase.

Twenty-six percent use the TrailPass because it makes travel convenient and another 14 percent use it because it eliminates the need for carrying cash. Some buyers suggested several additional reasons for using the Pass. These included parking availability and cost in Center City, free use of the other transit modes, and avoidance of driving during rush-hour traffic.

Perceived and Actual Savings

The average TrailPass buyer perceives a savings of approximately $18 per month. However, the actual savings computed on the basis of the number of trips actually reported (Questions 6 and 7) is nearly $33. This great underestimation of actual savings (approximately 83 percent) seems to indicate that TrailPass holders considered savings gained only on the commuter rail lines. Apparently, the use of buses or subway lines was not accounted for. It is interesting to note that some TrailPass holders indicated that they did not even know how to estimate their savings.

Nine percent of the users estimate their monthly savings to be less than $5, while 20 percent reported savings in excess of $25. Of the TrailPass users who ride 7 days per week, 35 percent save more than $15; only 9 percent of the 4- or-less days per week TrailPass users save as much. TrailPass buyers from the lower income groups enjoy higher savings than the buyers from the higher income groups because they use the TrailPass not only for work trips but for other travel purposes as well. For example, 50 percent of the TrailPass holders with incomes less than $15,000 save more than $15 a month, while only 40 percent of the TrailPass buyers with incomes over $50,000 save as much.

Weekly Usage of the TrailPass

The vast majority of the TrailPass buyers (84 percent) use the Pass 5 days per week. Only 13 percent use the Pass more than 5 days per week, while a small percentage (3 percent) use it less than 5 days per week. The average usage is 5.1 days per week. The highest average weekly usage was indicated by the buyers from the Terminal Zone (5.4 days per week).

TrailPass buyers with annual household incomes less than $25,000 enjoy higher than average usage (5.3 versus 5.1 days per week). The buyers from the $35,000-and-higher income group indicated the lowest weekly usage of between 5.0 and 5.1 days per week. Philadelphia has the lowest percentage (72 percent) of buyers using the Pass 5 days per week. However, as can be seen from Table 1 (based on responses to survey questions 5 and 13), Philadelphia has a higher percentage of resident TrailPass buyers riding 6 days per week than the suburban TrailPass buyers.

Frequency of TrailPass Usage on the Commuter Rail System

Most (74 percent) of the TrailPass buyers ride the commuter rail system 9 to 10 times per week. Fifteen percent ride from 11 to 13 times, while another 10 percent make more than 13 commuter rail trips per week. On the average, the TrailPass user makes 10.6 weekly commuter rail trips. The highest TrailPass weekly usage was indicated in Delaware and Philadelphia counties. The Terminal Zone Pass holders indicated the highest average usage--11.3 trips per week. This high usage reflects the high density of rail service operating in the Terminal Zone. The lowest average usage (10.0 trips) was indicated by the zone 5 Pass buyers. The TrailPass average weekly usage decreases as income increases. TrailPass holders with incomes under $15,000 make 11.1 trips per week compared to 10.2 commuter rail trips by TrailPass buyers with incomes over $50,000.

Frequency of TrailPass Usage on Transit Modes

As mentioned previously, the TrailPass enables the holder to ride any bus, subway, and streetcar route in addition to the commuter rail. Thus, nearly 8 of 10 TrailPass buyers indicated that they use the Pass to ride SEPTA's transit routes besides commuter rail. The majority (61 percent) of the TrailPass buyers use SEPTA's transit modes 8 or fewer times per week. Twenty-five percent of the TrailPass buyers use transit 9 to 10 times per week, while 7 and 4 percent ride the subway, buses, and trolleys 11-13 and 14-16 times per week, respectively. Sixty-three percent of these buyers ride the buses, subways, and trolleys to go to work, school, and other midday, work-related activities. Another 26 percent of the buyers use the Pass to go shopping, to lunch, and so forth, and 10 percent use the Pass to travel home from the commuter rail station.

Recommendations for Increasing TrailPass Sales

Nearly 40 percent of the TrailPass buyers recommended price reduction as a means of increasing sales. However, both parking privileges and the offering of weekly TrailPasses were favored by 19 and 14 percent of the buyers, respectively. An additional 10 per-

TABLE 1 Percentage of Resident TrailPass Buyers by County

No. of Days TrailPass Is Used per Week	Percentage of Residents by County					
	Bucks	Chester	Delaware	Montgomery	Philadelphia	Other
4 or less	2	1	4	3	4	3
5	93	94	81	90	72	89
6	4	5	12	6	18	8
7	1	0	3	1	6	0

cent recommended greater advertising to increase sales. This would make nontransit users as well as transit users aware of all the advantages of the TrailPass program.

There were some differences among the buyers' recommendations from the various fare zones (see Figure 3). For instance, more advertising was recommended by 20 percent of the buyers in the Terminal Zone but by only 5 percent of buyers in fare zone 5.

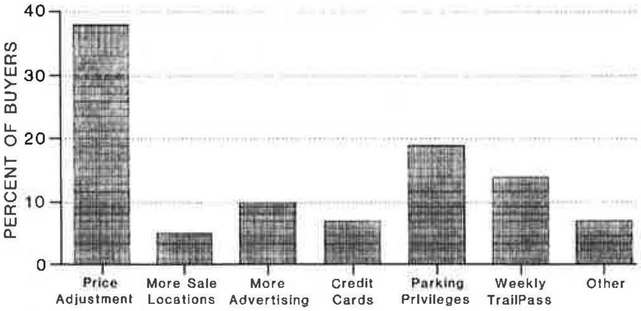

FIGURE 3 Percent of TrailPass buyers by buyers' recommendations.

Parking privileges were considered as important as money savings (35 percent) by TrailPass buyers in Chester County (fare zone 4), whereas only 11 percent of the Pass buyers in Philadelphia recommended parking privileges to increase sales. Some respondents recommended other strategies and actions that could increase the sales and use of TrailPasses. Following are the major suggestions:

1. Prepare a TrailPass lost-and-found policy that will clearly specify the information needed for refund or replacement.
2. Prepare complete information on the convenience, use, and benefits of the TrailPass and point out savings per month. Allow the use of credit cards at local stations. Offer more corporate discounts, especially to large companies with employee payroll deduction, and introduce discounts for students.
3. Provide free parking at stations, increase parking spaces at some stations and paved parking lots. Improve the appearance of some stations (i.e., remove graffiti) and clean train windows.
4. Run the trains on time. Increase the frequency of service and run more express trains from the outlying stations. Coordinate and update bus schedules to coincide with train service.

Travel Options in Case of TrailPass Discontinuation

In the event of TrailPass Program discontinuation, more than one-half of the present TrailPass buyers (57 percent) would seek other discount fares (10-trip tickets), and only 2 percent would buy daily tickets. Nearly one-third of the TrailPass holders would resort to the highway system and, of these, 18 percent would use cars or vanpools and 12 percent would drive alone. (These responses are shown in Figure 4.) The responses to this question are similar for the individual counties of the rail service area. However, the preferred travel options vary among the different income groups of TrailPass buyers as can be seen from Table 2 (based on responses to questions 9 and 12).

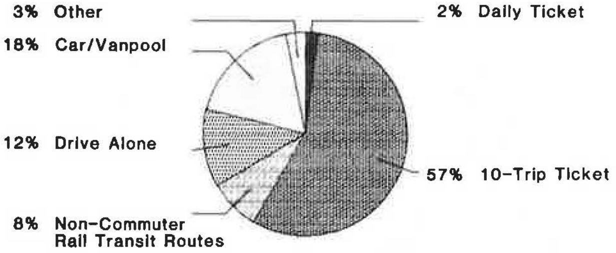

FIGURE 4 Percent of TrailPass buyers' options for alternative transportation means in the event of TrailPass Program discontinuation.

Age and Sex

The average age of the TrailPass buyer is 38. Sixty-nine percent of the riders are in the 18-44 age group and approximately 33 percent are in the 45-65 age group. Only 1 percent are over 65 or under 18. There are more female TrailPass buyers than male in the 18-34 age group (51 percent versus 38 percent), and more male buyers than female (27 percent versus 20 percent) in the 35-44 age group.

There is no significant difference between the total number of female and male TrailPass buyers (49 percent versus 51 percent) although, on the average, female TrailPass buyers are two years younger than male buyers. More than 50 percent of the female buyers are in the 18-34 age group while barely 40 percent of the male buyers are from this age group.

Annual Household Income

One-fourth of the TrailPass holders have an annual household income of $15,000-$25,000. An equal number (21 percent) of TrailPass buyers are in each of the three income groups over $25,000. The average TrailPass buyer's household income is $32,000 per year.

Nearly one-half of the TrailPass buyers from Philadelphia (48 percent) and Delaware (45 percent) Counties have an annual income of less than $25,000 a year, while the remaining counties have large

TABLE 2 Percentage of TrailPass Buyers Who Would Use Alternative by Type of Alternative and Annual Household Income

	Percentage of Buyers by Annual Household Income				
Alternatives to TrailPasses	Under $15,000	$15,000-$24,999	$25,000-$34,999	$35,000-$49,999	$50,000 or More
Purchase daily tickets	5	3	3	1	1
Purchase 10-trip tickets	45	56	57	56	65
Use other transit routes	14	11	6	6	4
Drive alone	12	10	11	15	15
Car or vanpool	19	18	20	19	14
Other	6	2	4	3	1

percentages of TrailPass buyer residents with incomes over $25,000. For example, 73 and 72 percent of the TrailPass buyers from Montgomery and Chester Counties, respectively, have annual incomes of over $25,000. The percentage of female TrailPass buyers in each income group declines as the income increases. Seventy-two percent of the female TrailPass holders have annual incomes under $15,000, while only 34 percent have annual incomes over $50,000.

FINDINGS AND CONCLUSIONS

The survey yielded the following data:

1. The TrailPass patrons are consistent buyers--nearly 97 percent purchase their Passes regularly;
2. Money savings were cited as the principal reason for buying the TrailPass--approximately 91 percent of the buyers save more than $5 per month;
3. Convenience and time saving were indicated by the buyers as other major reasons for purchasing the TrailPass;
4. The buyers recommended price reduction as a way to increase sales; however, both parking privileges at stations and the issuing of weekly TrailPasses were significantly favored by the buyers;
5. If the TrailPass program was discontinued, more than one-half of the buyers would seek another discount program (10-trip ticket). Vans and carpools would be chosen by 18 percent of the TrailPass buyers, while 12 percent would drive alone;
6. The average TrailPass buyer is 38 years old;
7. There is no significant difference between the number of female and male TrailPass buyers; and
8. The average household income of the buyers is $32,000 per year.

Because they regularly commute to work, the overwhelming majority of the buyers use the Pass 5 days a week. A TrailPass user makes about 10.6 commuter rail trips per week. The majority of the Pass buyers use the TrailPass an average of 6.9 times a week to ride other SEPTA modes. The TrailPass is used for making many trips on the transit system that would not be made if the TrailPass were not available (such as lunch hour or weekend shopping trips). The survey indicated that the TrailPass program increases the mobility of the lower income groups, particularly those who live in dense urban areas.

The survey also indicates that the TrailPass program can be beneficial to passengers as well as transit operators because it saves time and money. In addition, it advances cash flow, reduces the operating cost involved in administering cash fares, and makes the transit system more attractive and affordable for passengers. It can be applied successfully in any large region with extensive commuter rail network similar to the Philadelphia system.

ACKNOWLEDGMENT

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BART Impact Update

JOEL E. MARKOWITZ

ABSTRACT

When representatives of the multi-year, multi-million dollar San Francisco Bay Area Rapid Transit (BART) Impact Program presented their conclusions to the TRB Annual Meeting in January 1979, BART had not yet achieved a reliable level of operation. The findings had been based on data gathered in the early period of full-system operations (1974-1977). The thrust of the findings was that hoped-for impacts of BART on travel had not materialized because of the constraints on BART operation and the limited market BART was focused on. These and even earlier findings by a university research group have been widely quoted in the literature and used in textbooks. This paper contains documentation as to what has happened with BART use and travel in the primary BART service corridor since 1978, and an illustration showing that many of the earlier constraints on BART patronage and, thus, its impact, have been relieved. BART's service reliability has improved dramatically, attracting many new patrons, and population and employment in BART's market area have grown. As a result, BART carries a large share of trips in its intended market--long-distance commute trips to the urban core.

It is difficult in some circles even to bring up the subject of the impact of the San Francisco Bay Area Rapid Transit (BART) system (see Figure 1) without immediately polarizing those individuals present. The debates began from the earliest findings of the BART Impact Program, the elaborate federally funded study that was conducted from 1972 to 1978. In 1976, a university research group published its interpretation of the early results, and those largely negative findings have found a permanent place in the transportation planning literature (1-4) and in textbooks (5,6). Transit professionals with an interest in rail transit development responded in their own professional journals (7,8).

It was not until late 1978 that the formal BART Impact Program concluded with a full-day presentation of findings to the TRB Annual Meeting in January 1979. The production of final reports continued into 1979, and the fifteen project reports and final Program summary report were not broadly distributed until late 1979 (9). By that time, the debate had cooled, but its impact could be seen in each of the Program reports. The "Sponsor's Note" ("Sponsor" meaning the U.S. Department of Transportation), which appears at the front of each report carefully lays out the circumstances surrounding the study, its limits, and the factors affecting the findings. The 2-page caveat incorporates many of the key points of the debate--special institutional setting in the Bay Area, system not running at full service levels, short period of operating experience, etc.

One methodological recommendation of the BART Impact Program was for continuation of a low-level, long-term monitoring program. There was little interest in pursuing the suggestion, except for continuing the semi-annual counts of vehicle and person traffic across the San Francisco-Oakland Bay Bridge corridor, the primary BART service route. For lack of a comprehensive approach to updating all the major findings on the impacts of BART, the following pages contain information concerning only the trends in BART travel and the patterns in the Bay Bridge corridor. Even this modest update may help inject some new information into the on-going debates concerning rail transit (10).

BART DESCRIPTION

In one sense, not much has changed since the BART Impact Program concluded. There are still 34 BART stations, 71 mi of track, 450 cars, and 23 parking lots with approximately 22,000 spaces. The fare is still distance-based and collected automatically, although fare increases have boosted the range from $0.25-$1.45 reported in 1978 to $0.60-$2.15 in 1984. The BART patron is still more highly educated and more affluent than the general public, reflecting still the high degree of BART use for suburbanites' work trips (see Table 1). The average trip length is still approximately 13 mi, although the true trip-length distribution is approximately evenly bimodal--a short-distance peak at 6-8 mi and a trans-bay peak at about 20 mi. The 13-mi "average" is an artifact of that distribution and, in fact, there are few 13-mi trips on the system.

In another sense, though, BART is a very different system from that studied from 1972 to 1978. Minimum peak-period headways are now under 4 min instead of 6 min. Revenue car availability at the start of morning peak service has climbed from 60 percent in fiscal year (FY) 1975-1976 to 90 percent in FY 1983-1984. Unscheduled train removals have been cut from 17.3 per day in FY 1975-1976 to 2.2 in FY 1983-1984. Consequently, there has been nearly a 33 percent increase in the number of car-miles of service provided. The result has been an increase over that period of more than 60 percent in passenger trips and over 75 percent in passenger-miles. This has allowed the farebox recovery ratio to climb from 39 percent to 49 percent while cost per passenger mile has remained flat at $0.15-$0.16 despite inflation (see Table 2). Though BART's operating cost per passenger-mile is similar to that of other U.S. rail systems, its cost per passenger is relatively high. This is due in part to its long average trip length (see Table 3).

BART PATRONAGE TRENDS

BART patronage has been sensitive to external events, such as transit labor disputes (its own and others)

FIGURE 1 BART system map.

and sudden changes in gasoline price and availability. Still, there has been a steady growth in BART's primary transbay market. Figures 2 and 3 show the trend in BART's average daily patronage each month from September 1974 (the month the Transbay Tube was opened) to July 1985. Trips in the East Bay (Alameda and Contra Costa Counties) have grown from about 40,000 to 50,000 trips per day, while West Bay trips (San Francisco and Daly City) have grown from 30,000 to 50,000. A jump in West Bay trips occurred in April 1983 with the introduction of a joint BART/San Francisco Municipal Railway monthly pass. Transbay trips have grown from 50,000 to over 100,000. Transbay trips now comprise 50 percent of all BART trips. The proportion of BART trips in the morning and evening peak periods, however, has changed little, from 45-50 percent in the early years to 50-55 percent now. Figure 2 shows each of the three major market components separately, with the West Bay and East Bay components now almost equal. Figure 3 shows the contribution of each market to BART's cumulative patronage. (Note that BART average weekday patronage data are taken from BART's monthly patronage reports. The following events affected patronage:

November 1975-fare increase
April-May 1976-San Francisco MUNI labor dispute
September 1977-BART labor dispute
November 1977-January 1978-AC Transit labor dispute
January-April 1979-Transbay Tube closed by fire
May 1979-"gasoline crisis"
August-November 1979-BART labor dispute
July 1980-fare increase

TABLE 1 BART Passenger Characteristics

Characteristics	1976	1978	1980	1980 Census	1982
College graduates (%)	40.8	44.0	45.4	24.9	46.4
White (%)	76.5	74.6	67.2	62.9	68.2
Annual incomes over $20,000 (%)	35.7	47.1	53.7	47.1	66.0
Age 35 or older (%)	38.8	43.6	44.3	44.2	44.4
Work trips (%)	65.5	74.2	74.4		77.4

Note: The BART passenger data are from BART's series of Passenger Profile Surveys, and the census data are averaged for the three BART counties.

TABLE 2 BART Financial and Operating Characteristics, 1976-1984

	Fiscal Year								
Characteristics	1976	1977	1978	1979	1980	1981	1982	1983	1984
Net operating expenses (million $)	55.126	66.814	78.204	86.548	88.457	103.256	117.820	125.281	134.046
Fare revenues (million $)	21.714	24.692	28.219	28.727	25.942	46.207	52.677	60.965	65.492
Farebox ratio (%)	39.4	37.0	36.2	33.2	34.4	45.3	45.2	49.1	48.9
Average fare ($)	0.708	0.738	0.723	0.685	0.733	0.964	0.988	1.110	1.10
Cost per passenger mile ($)	0.133	0.146	0.155	0.166	0.155	0.155	0.154	0.162	0.166
Car miles	22,446,355	22,862,970	24,046,898	26,806,000	20,046,000	27,707,000	28,505,000	29,177,000	29,852,000
Unscheduled train removals per day	17.3	11.7	10.1	9.0	8.1	7.8	5.3	4.5	2.2
Revenue car availability (%)	60	76	87	82	76	83	86	89	90
Total passenger trips	32,897,431	34,599,088	38,665,206	41,191,566	34,482,335	46,879,319	53,290,643	53,699,387	58,277,463
Passenger miles	414,507,631	444,401,162	492,901,000	500,221,000	443,085,000	626,662,000	717,998,000	725,077,000	761,799,000
Average trip length (mi)	12.6	12.8	12.7	12.1	12.8	13.4	13.5	13.5	13.1

Source: Annual Reports of the San Francisco BART District.

TABLE 3 U.S. Rail System Characteristics *(11)*

Operator	Trip Length (mi)	Expense per Trip ($)	Expense per Passenger-Mile ($)
BART	12.5	2.168	0.173
Rapid rail systems			
New York City (CTA)	4.2	1.009	0.242
Chicago (CTA)	7.3	1.274	0.175
Philadelphia (SEPTA)	5.5	0.938	0.171
Boston (MBTA)	3.0	1.012	0.333
Washington, D.C. (WMATA)	4.3	1.282	0.296
Cleveland (GCRTA)	7.8	1.339	0.171
Atlanta (MARTA)	3.3	0.514	0.156
Lindenwold (PATCO)	8.7	1.518	0.174
Group average	5.5	1.111	0.215
Commuter rail systems			
Chicago (RTA)	19.9	3.330	0.167
Philadelphia	11.6	17.626	1.517
Boston	18.7	4.304	0.230
Detroit (RTA)	18.2	10.495	0.577
New Jersey (NJT)	23.3	4.858	0.165
Pittsburgh (PAT)	14.9	5.572	0.374
Group average	17.8	7.531	0.505

Other than the preceding incidents, missing data account for some of the zero points in Figures 2 and 3.)

The noted improvement in the quality and quantity of BART's service is one factor promoting patronage, but there are others. Figure 4 shows data on the growth in population in the three BART counties since 1974, which was taken from the California Department of Finance. In the period studied by the Impact Program, San Francisco's population was declining while the East Bay's population was relatively flat. Since then, all three counties have grown, with suburban Contra Costa County (a large transbay commute market) growing the fastest.

Figure 5 shows data on employment growth in the larger metropolitan area, where most of the workplaces are within the three BART counties. (The data were taken from the California Employment Development Department.) Substantial growth has occurred (nearly 40 percent) since 1975 in the service and finance categories, both of which are well-represented in the central urban areas served by BART.

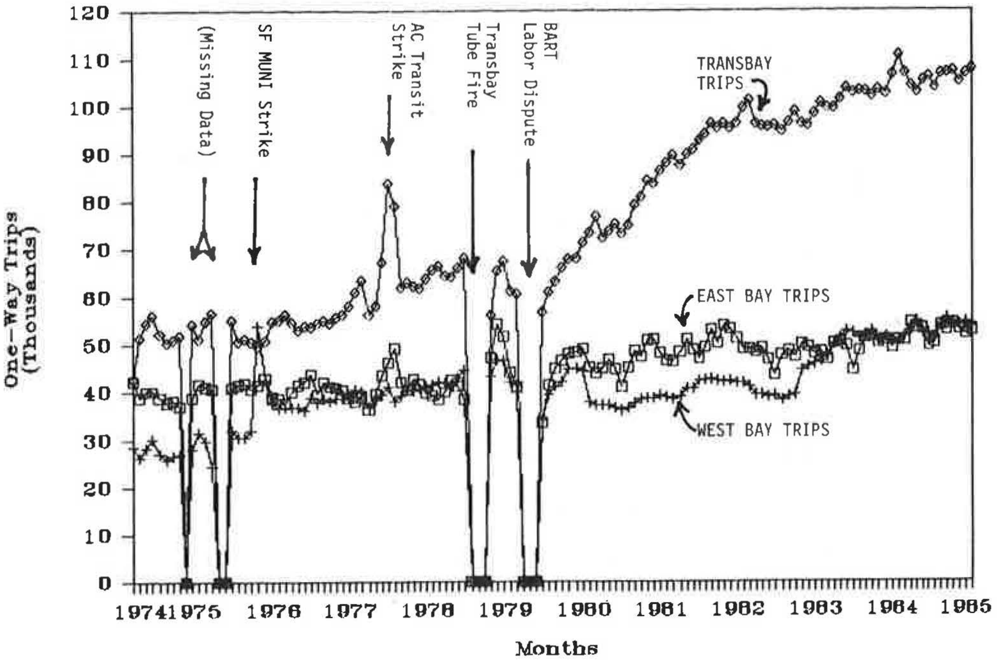

FIGURE 2 BART patronage by market (markets shown separately).

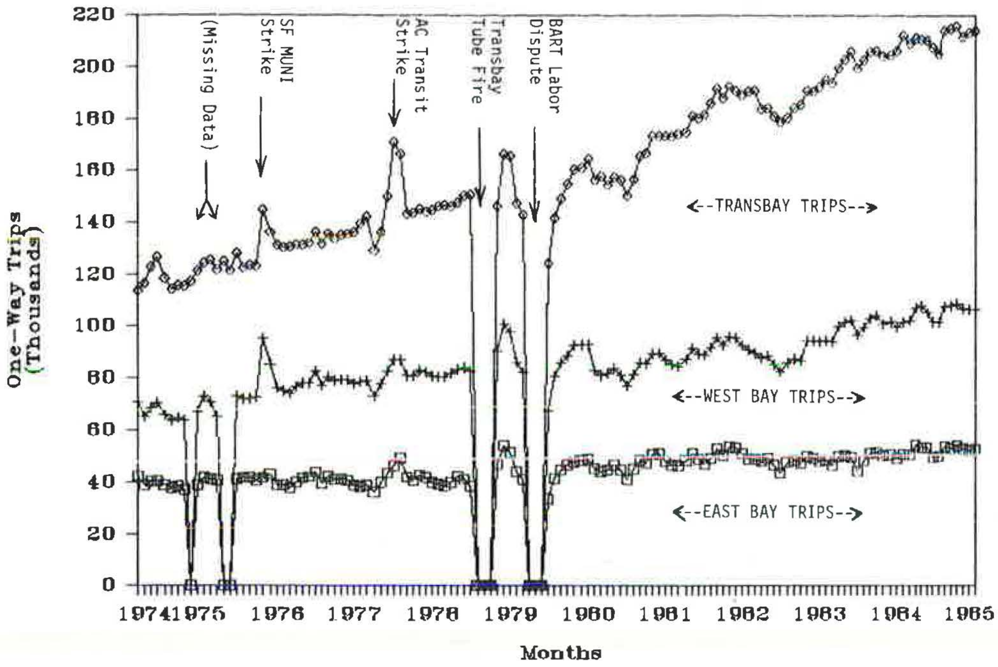

FIGURE 3 BART patronage by market (markets shown cumulatively).

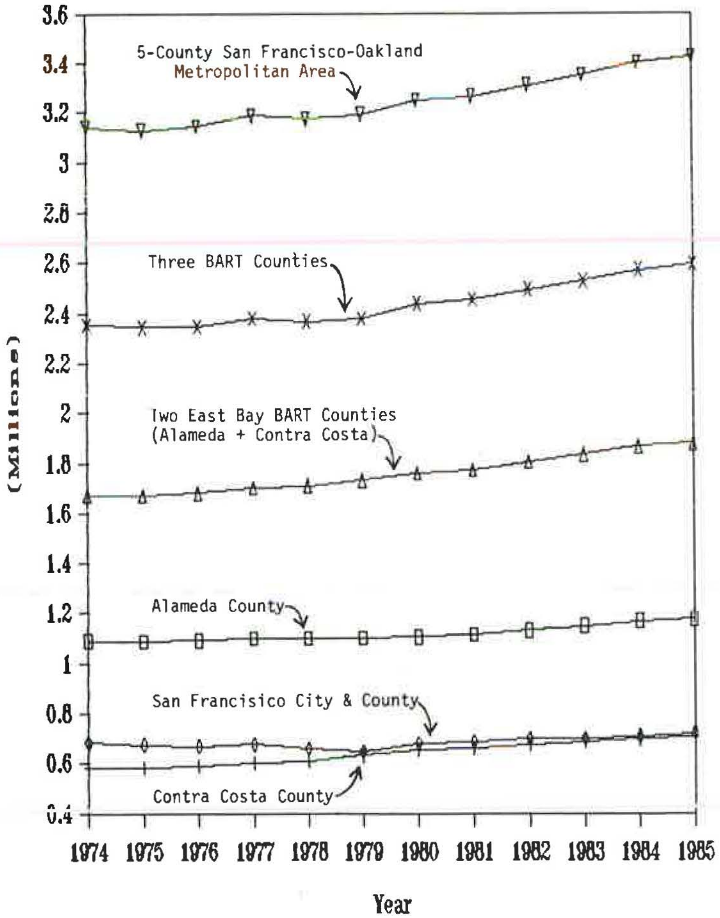

FIGURE 4 BART area and regional population—1974-1985.

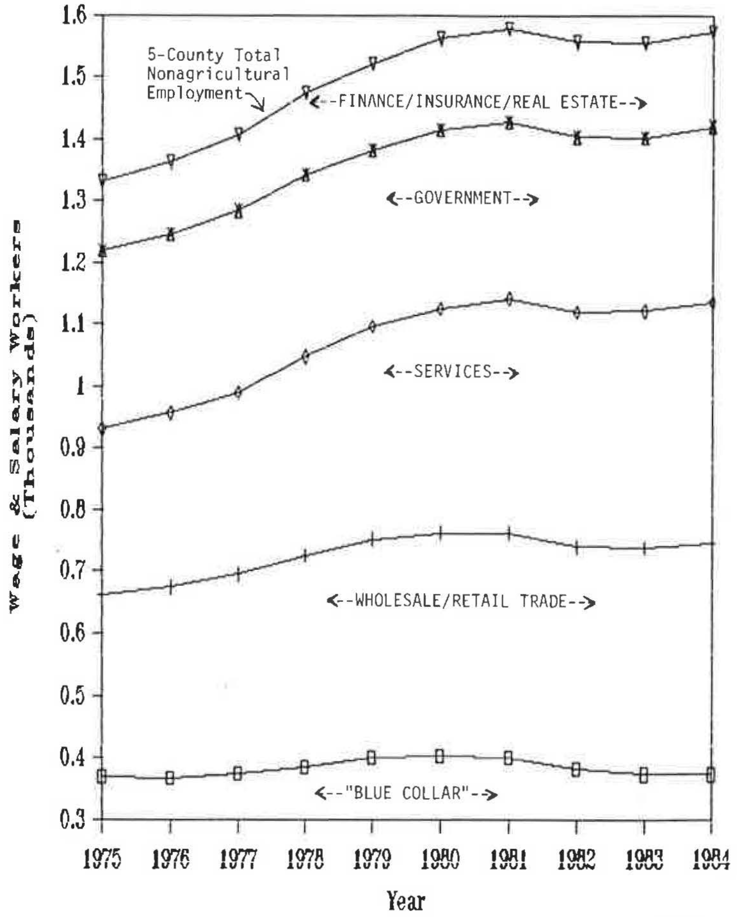

FIGURE 5 San Francisco-Oakland metropolitan area employment—1975-1984.

Finally, Figure 6 shows the change in unleaded, self-service, gasoline prices in Northern California for each December since 1975. The dramatic increase of 1979-1981 occurred after the conclusion of the BART Impact reports.

The final report of the BART Impact Program's study of transportation impact noted potential sources of future patronage growth and cited limits to that growth. The principal limits were seen as BART's unreliability, slow growth of jobs and population in its service area, and continuing dependence on the automobile (12). Since 1978, these constraints have apparently been reduced--reliability is greatly improved, population and jobs have increased, and the price of gasoline has somewhat reduced the attractiveness of automobile travel.

BART has ambitious plans for expanding service through the remainder of the decade. These plans include: (a) increasing the number of cars in the fleet to 489 (an increase of 150 cars), (b) increasing the maximum number of trains in service from 43 to 74, and (c) reducing the minimum scheduled headway from 3 min and 45 sec to 2 min and 15 sec. Two major capital improvements are underway to help achieve these goals. Currently, BART is completing an additional subway track through downtown Oakland to increase operational flexibility and reliability. Funding has just begun for a turnback facility and storage yard beyond the Daly City Station, the western terminus of the line through San Francisco. BART projects that if these and other improvements are in place by 1989, patronage will increase to 285,000 trips per weekday--an increase of 30 percent (13).

BAY BRIDGE TRAFFIC

What of BART's effects on highway travel? The BART Impact Program found that BART's contribution to the relief of congestion in the Bay Bridge corridor, the principal link between the East Bay and San Francisco, was short-lived. The attractiveness of downtown San Francisco as an employment center has increased, not diminished, since 1978. The demand for travel in that corridor in the morning peak period has increased 40-50 percent since the opening of BART's Transbay Tube in September 1974. Figure 7 shows the long-term trend in westbound, a.m. peak-period person trips by mode since 1970. Some 75,000 persons cross the Bay by automobile, bus, or BART each morning, compared to 50,000-55,000 in 1974. The steady increase in person-trips was interrupted only briefly in 1979 with the large increase in gasoline prices. As Figure 8 shows, the increase in westbound transbay travel demand is true for the entire 24-hr day, not just for the peak period. From 1975 to 1985, vehicle trips increased 22 percent (from 94,000 to 115,000), while transit person trips increased 43 percent (from 45,000 to 66,000) and total person trips increased 34 percent (from 174,000 to 233,000).

The demand may have increased dramatically, but the bridge is still only five lanes wide in each direction. The peak demand has been spread in three of the only four ways possible: (a) motorists are filling in the shoulders of the peak, (b) automobile occupancies have climbed and (c) BART is carrying more of the load. The fourth alternative is the use of buses; however, there has been a decline in both

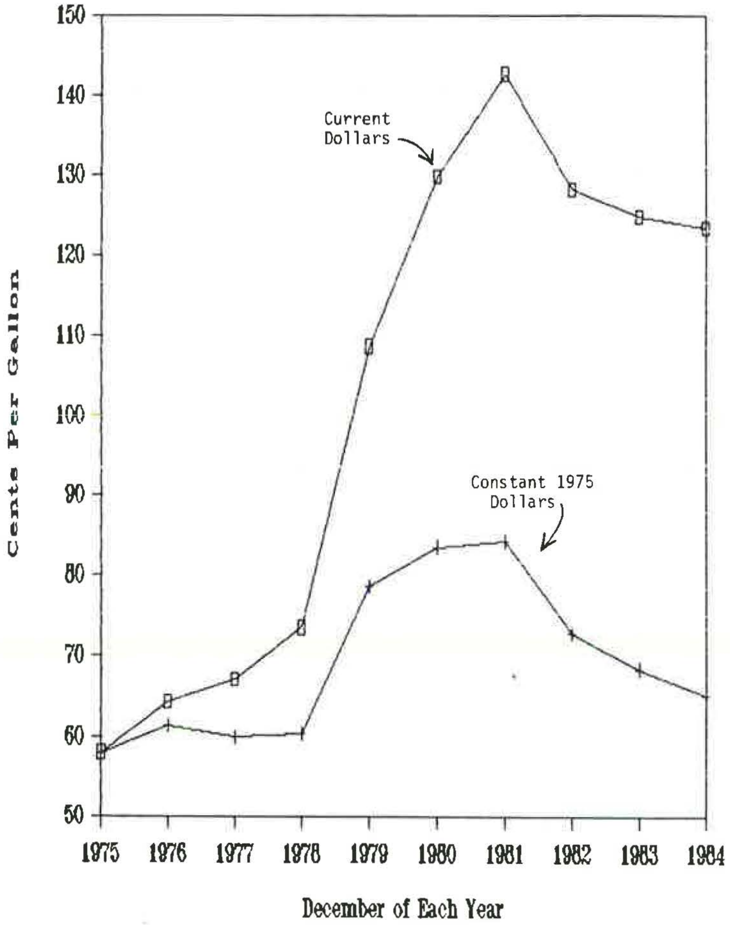

FIGURE 6 Gasoline prices.

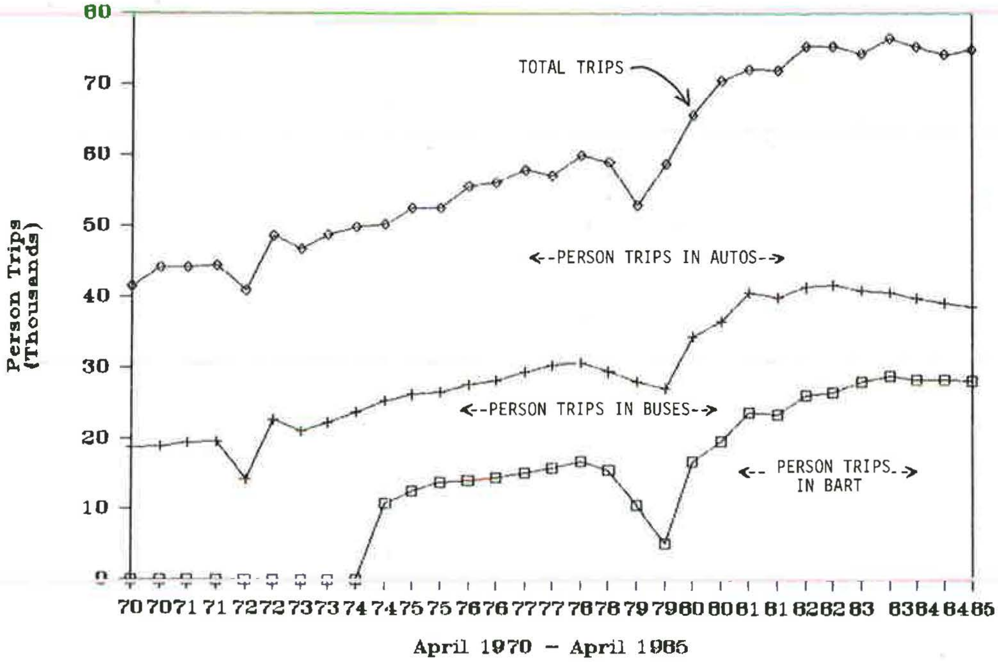

FIGURE 7 Bay Bridge a.m. peak traffic, 1970-1985 (note that there were two observations per year—in April and October—and the a.m. peak is from 6:30-9:00).

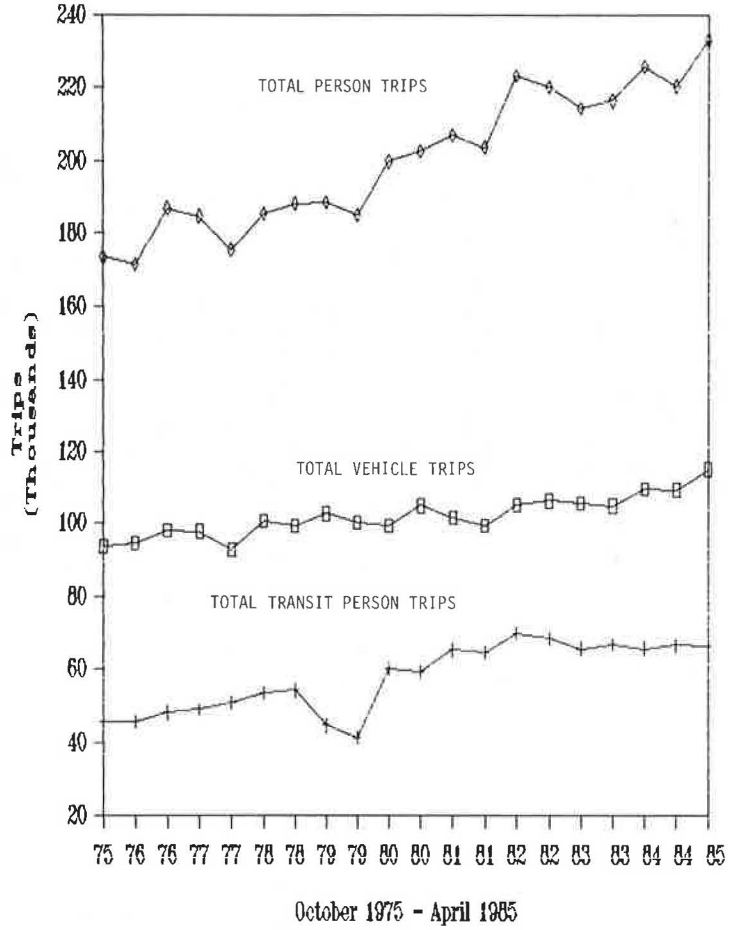

FIGURE 8 Bay Bridge 24-hr traffic, 1975-1985 (note that there were two observations per year—in April and October).

magnitude and proportion of bus riders carried in the transbay corridor. Figure 9 shows the change in the shape of the peak for westbound, a.m. peak-period vehicle traffic since 1974. Each of the twice-yearly observations--October and April--show the vehicle traffic by 30-min increments from 6:30 to 9:00 a.m. Over time, the earliest 30-min period has grown to equal the second 30 min period and all traffic from 6:30 to 8:00 has gradually crept up to the theoretical limit of the bridge's capacity. Bridge planners typically use a figure of 1,800 vehicles per lane per hour, which translates into 4,500 vehicles per 30-min period. The October 1980 data point in the middle of the peak in Figure 9 is therefore suspect because it exceeds that capacity by several hundred vehicles.

Figure 10 shows that automobile occupancy has increased considerably in the westbound, a.m. peak-period from the 1974 average of 1.4 passengers to the 1985 average of 1.8 passengers. Incentives for car- and vanpooling may have had an effect, including reserved toll-free high-occupancy vehicle (HOV) lanes through the Bay Bridge toll plaza during the peak. The usual toll is $0.75 ($0.60 with a commute ticket book) in the westbound direction, but a more significant incentive may be the reserved lanes, which have been estimated to save as much as 10 to 15 min in travel time during the most congested periods. (Note that for Figures 9 and 10, there were 2 observations made per year--in April and October--and the a.m. peak period is from 6:30 to 9:00. Note also that the 5 vertical bars for each year represent 30-min a.m. peak period increments as follows: 6:30-6:59, 7:00-7:29, 7:30-7:59, 8:00-8:29, and 8:30-8:59.)

Figures 11 and 12 show the share of westbound, a.m. peak-period person trips now being carried by each mode in the a.m. peak. Figure 11 shows the absolute number and Figure 12 shows the percentage share. With the filling in of the peak and the increases in automobile occupancy, the share of person trips in transit has grown moderately from 50 percent in 1974 to 52 percent in 1985. BART's share has grown from about 20-25 percent to 35-40 percent because of diversion from buses and growth in its Contra Costa County market area.

It should be noted that Figures 7-12 are based on a series of counts conducted by the University of California, Berkeley, Institute for Transportation Studies of the California Department of Transportation for the Metropolitan Transportation Commission. Methods changed somewhat over time. The dates selected for counts are "typical" mid-week days in October and April. The traffic counts are done for only one or two days and the transit data are collected from the appropriate agencies for those days. Some changes in bridge operations during the period also affected capacity, including a toll increase in July 1977, changes in the placement and hours of carpool lanes and the operation of metering lights.

Is the Bay Bridge peak congestion lessened by BART? No, but the answer depends on perspective. Without BART, it seems unlikely that the bridge could support the current level of peak trip making in the corridor, although certainly some increased portion could be carried by additional buses. For

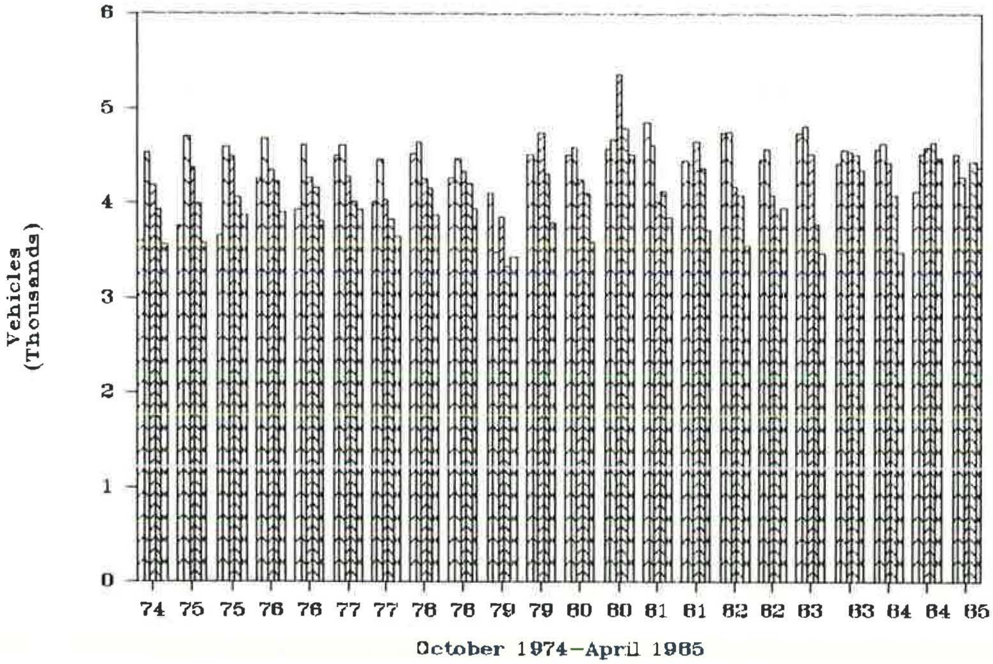

FIGURE 9 Bay Bridge a.m. peak vehicle traffic, 1974-1984.

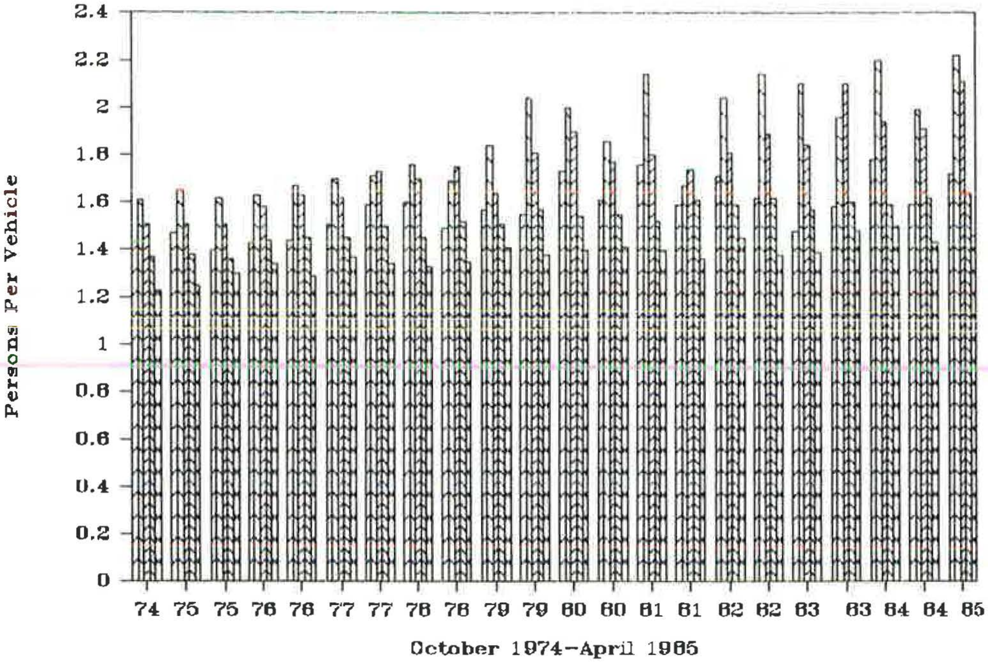

FIGURE 10 Bay Bridge a.m. peak vehicle occupancy, 1974-1984.

example, to carry the 28,400 April 1984 BART peak-period patrons in buses would require over 730 additional bus trips at typical peak loads, compared with only 336 actual bus trips, and 610 bus trips in 1974, before transbay BART service began. The 730+ vehicles, on top of the actual peak vehicle load, would have pushed three of the 30-min periods over the theoretical bridge capacity and a fourth period within 5 percent of that limit. Whether the level of demand itself would be lower without BART is a matter of conjecture beyond the scope of this summary.

Those who hoped for traffic congestion relief from BART may have made a heroic assumption: that travel demand would remain constant in the busiest corridor in the region that serves one of the most desirable central business districts in the nation, in an area with a vigorous economic, population, and white-collar employment growth. The good news is that BART has helped satisfy that demand for travel; the bad news is that the demand is excessive, causing continued congestion. Hindsight suggests this should have been no surprise. Similarly, hoped-for benefits in the areas related to traffic congestion relief, such as air pollution reduction, cannot be detected because BART travel is still a small fraction of total regional trip-making.

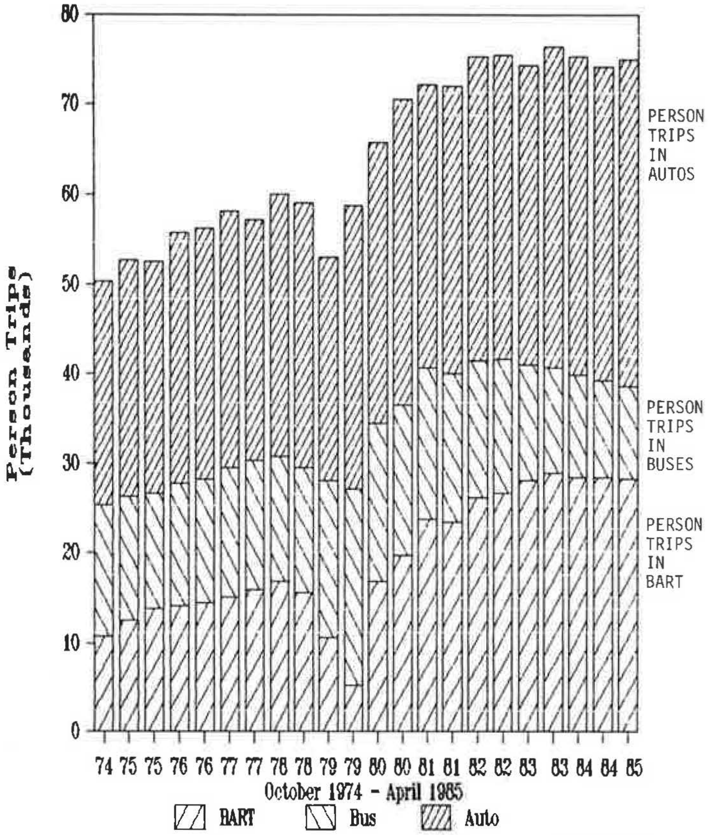

FIGURE 11 Bay Bridge a.m. peak person trips by mode, 1974-1984.

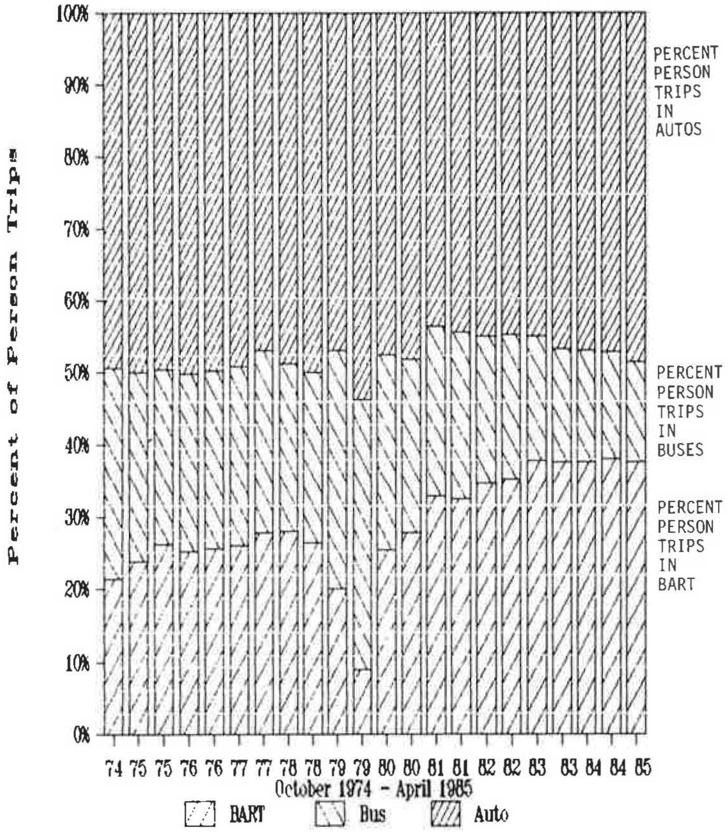

FIGURE 12 Bay Bridge a.m. peak person trips modal shares, 1974-1984.

CONCLUSION

This brief review was not intended to be a comprehensive examination of all aspects of BART's impacts, nor even a detailed statistical analysis of transportation and travel impacts. Reliance on descriptive material and graphs is intended only to provide some basic information to update the largely outdated material from the early BART Impact Program findings and other sources from the early 1970s from which many individuals still seem to be quoting. The material briefly presented here demonstrates that BART's performance and patronage have improved dramatically since the early reports were published. While hardly the panacea for the Bay Area's urban transportation problems, BART has increased its effectiveness in serving its primary intended market--the long-distance commute trips to the urban core. The debate on new rail transit systems and extensions will continue, and there will always be a demand for information on BART as a referent for that debate. This paper can contribute only modestly to that demand.

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The Effects of Fare-Collection Strategies on Transit Level of Service

UPALI VANDEBONA and ANTHONY J. RICHARDSON

ABSTRACT

It is known that different fare-collection strategies have different passenger boarding and alighting rates for street-based public transport services. In this paper, various models of stop service times are reviewed, the available empirical observations of boarding and alighting rates are summarized, and the effects of different average boarding rates and coefficients of variation of boarding rates on the route performance of a tram (light rail transit) service are examined. The analysis is conducted using the TRAMS (Transit Route Animation and Modeling by Simulation) package. This modeling package is briefly described with particular attention to the passenger demand subroutine as well as the tram stop service times subroutine. As a result of the analysis, it was found that slower boarding rates produce a slower and less reliable service along the route. The variability of boarding rates has no effect on route travel time but does contribute to greater unreliability in level of service. It is concluded that these level-of-service effects need to be considered when assessing the effect of changes in fare-collection strategies.

Public transport operators and managers have found themselves under increasing pressure in recent years because of conflicting expectations from different groups in the community. On the one hand, public transport users demand better levels of service and no increase in fares, while the general community and the Government Treasury demand that the public transport financial deficit be reduced, or at least curtailed. Given these pressures, public transport managers are continually looking for methods by which the productivity of the public transport system may be enhanced.

In the field of street-based public transport, a subject that has received much attention in this respect is staffing policy; in particular, the debate over whether to have a one- or two-man operation of public transport vehicles has been both lengthy and vigorous in Australia and elsewhere. Investigations of one-man operations have covered not just staffing policies, but also vehicle design and fare-collection strategies. All three must be well-integrated if an acceptable one-man operation system is to be devised.

In considering this question, it is obvious that the effects of a one-man operation go well beyond the immediately apparent staff cost savings. In particular, the choice of fare-collection strategy has a large influence on whether conversion to a one-man operation will ultimately prove to be beneficial or not. If boarding the vehicle is slowed by the one-man operation, fare-collection strategy, then it is possible that the degradation in the level of service provided will outweigh the immediate staff cost savings per vehicle so that the service is less productive overall. Obviously, conversion to a one-man operation needs careful analysis of the operational, financial, and economic consequences. Even in situations such as in North America, where all transit services are already one-man operations, it is important to consider the effects that different fare collection strategies will have on the level of service provided. The conversion of pay-the-driver systems to proof-of-payment systems will generally bring about significant level-of-service improvements that should be considered in any analysis of such fare collection strategies.

This paper makes a contribution to this analysis by examining the effects of different boarding rates on the route performance of a light rail transit (tram) system. Boarding rates are a critical variable in that they most concisely describe the operational performance of different fare-collection strategies, as well as different vehicle designs. Route performance is expressed in terms of average passenger travel time, average passenger waiting time, vehicle bunching, route travel time, and a number of other level-of-service performance measures. The analysis is performed using the TRAMS (Transit Route Animation and Modeling by Simulation) package (see paper by Vandebona and Richardson elsewhere in this record), and uses a case study example loosely based on an actual tram route in Melbourne, Australia.

FARE-COLLECTION STRATEGIES

Fare-collection strategies for street-based public transport may be classified under three major headings: (a) two-man operation where the conductor collects fares, (b) one-man operation where the driver collects fares, and (c) one-man operation where the driver does not collect fares. Within each of these classifications, there are a number of different alternatives. In the two-man operation, the conductor may function in one of two ways--either as a roving conductor who moves through the vehicle collecting fares from passengers while the vehicle is in motion, or seated with passengers paying their fares as they file past the conductor's position after entering the vehicle.

A one-man operation with fare collection by the driver gives rise to a wide range of boarding time rates, depending on the details of the fare-collection procedure and the nature of the fares charged. Two major options for fare collection are to accept exact fares only or to enable the driver to give change to passengers. As will as seen later, the former results in a faster boarding rate, while the latter is more conducive to good customer relations. The degree of difference between these two options also depends on the nature of the fares charged. For example, are they flat fares, finely graduated fares according to the distance traveled, zone fares, free transfers requiring no extra ticket purchase, or season tickets? Each of these alternatives will have different boarding rates and, hence, different impacts on the route performance of the service. A one-man operation with fares not collected by the driver means that fares must be collected in some other fashion--unless, of course, the public transport service at the point of usage is free to users. One of the most popular methods of automatic fare collection is the exact-change fare box. This method has been in use in North American services for many years. A minor, though important, aspect of this system is whether the fare is single-coin or multiple-coin; single-coin fares give slightly faster boarding rates but are becoming increasingly difficult these days. Watts and Naysmith (1) note the need for a coin of value greater than 50p (in the United Kingdom). Other methods of payment include the use of pay-turnstiles on board the vehicle (although these are often seen as being an unreliable hindrance), and the use of credit card and magnetized ticket-reading machines.

A complete alternative to the previous methods is the "proof-of-payment" system, in which there are no turnstiles or barriers to entry and no need for any fare payment on boarding the vehicle. All that is required is that the user have a valid ticket that must be produced if required. Ticket inspectors perform random checks for fare evasion, and the penalty imposed must be such that the expected cost of purchasing a ticket be no more than the expected cost (including penalties) of not purchasing a ticket. Given this general approach to fare collection, the range of ticket-selling procedures is quite wide. Season tickets could be used, books of tickets could be bought from news agents or other stores; tickets may be purchased from ticket-sellers at major stops, ticket-selling machines (either at stops or aboard the vehicle), or drivers (at a premimum price); or users could simply elect to pay the penalty when caught without a ticket. In a proof-of-payment system, with appropriate penalty charges and a systematic ticket inspection roster, this last method of payment would be legitimate and need no longer be thought of as a crime of fare evasion.

A major advantage of the proof-of-payment system is that it results in a quick boarding rate and, hence, a higher level-of-service to users. It also allows considerable freedom in vehicle design because there is now no need for all boarding passengers to file past the driver. Wide central doors and articulated vehicles become distinct possibilities. A disadvantage of proof-of-payment systems is that operators can no longer obtain ridership statistics from ticket sales, and may therefore have to conduct special sample surveys to obtain ridership details.

BOARDING AND ALIGHTING RATE MODELS

Given the wide variety of fare-collection strategies and associated vehicle designs, it is not surprising that a number of different models have been proposed to predict service time at a stop as a function of the numbers of passengers boarding and alighting from the vehicle at that stop. In summary, there are four basic models that have been proposed for the prediction of service times.

The Sequential Model

$$T_i = \gamma + \alpha A_i + \beta B_i \tag{1}$$

where

T_i = service time at stop i,
A_i = number of alighting passengers at stop i,
B_i = number of boarding passengers at stop i,
γ = dead time,
α = alighting time per passenger, and
β = boarding time per passenger (sec).

This model is likely to be appropriate where boarding and alighting take place through the same door and, hence, proceed sequentially (alighting usually preceding boarding). The dead time, γ, accounts for the time lost at the beginning and end of the stopping maneuver and is a function of the presence or absence of doors on the vehicle, the nature of any door interlocking device fitted to the vehicle (e.g., a transmission interlock that prevents doors from being opened until the vehicle is stopped and an acceleration interlock that prevents the vehicle from moving until the doors are closed), and the layout of the stop (e.g., safety-zone boarding versus curb-loading). The coefficients α and β depend primarily on the fare collection system employed, but may also vary with the time of day (peak versus off-peak), and with the type of passenger being served (e.g., elderly or infirm), the current occupancy of the vehicle, and the amount of baggage carried by passengers.

The Interaction Model

$$T_i = \gamma + \alpha A_i + \beta B_i + \delta (A_i \cdot B_i) \tag{2}$$

This model is again applicable to a single-door vehicle but instead of assuming complete independence between boarding and alighting events, it allows for the possibility of interaction between the two streams of passengers. The coefficient δ may be either positive or negative, accounting either for conflicting and congestive effects or for overlapping boarding and alighting flows.

The Simultaneous Model

$$T_i = \max \begin{bmatrix} \gamma_A + \alpha A_i \\ \gamma_B + \beta B_i \end{bmatrix} \tag{3}$$

This model is appropriate when the vehicle has separate doors for boarding and alighting. In this case, both processes may occur simultaneously and the service time will be determined by whichever process takes the longer time. In this model, different dead times are allowed for boarding and alighting processes to account for the effect of different types of door interlocking devices.

The Multi-rate Boarding Model

$$T_{Bi} = \begin{cases} \gamma + \beta_1 B_i & 0 < B_i < x \\ \gamma + \beta_1 x + \beta_2 (B_i - x) & x < B_i \end{cases} \tag{4}$$

Under some circumstances, in any of the first three models, the boarding time (T_{Bi}) may best be explained by means of a multi-rate boarding process. Thus, for the first x boarding passengers, boarding takes place at a rate of β_1 sec per passenger. Above this number, extra passengers board at a slower rate of β_2 sec per passenger. This situation may occur, for example, when boarding passengers must pay fares at a turnstile or to a seated conductor situated inside the vehicle, and where there is only enough queuing space for x passengers within the vehicle.

SOME EMPIRICAL OBSERVATIONS

In all of the previous models, the parameters α, β, γ, and δ must be determined by empirical observation. Surprisingly, for such a basic measure of public transport vehicle performance, there is little evidence of reported studies in the transport literature. One major United Kingdom study (2) and one major United States study (3) as well as a number of smaller studies comprise the major literature on the subject. Some limited information on the Melbourne tram system, which is the subject of the case study in this paper, is also available (4). While although the analysis reported later in this paper is not dependent on particular values of boarding and alighting rates, it is informative at this stage to review the empirical values reported in the literature for different vehicle design and fare-collection strategy configurations, so that an idea of the range of values likely to be met in practice can be obtained.

Cundill and Watts reported on a major study of bus boarding and alighting times carried out in various cities in the United Kingdom (2). Their study covered a wide range of bus designs and fare-collection strategies. They found that a linear sequential model was satisfactory for one-door buses while a simultaneous model described a two-door operation. They found that the alighting rate was similar for all vehicles studied with values ranging from 1 to 1.6 sec. Boarding rates ranged from 1 to 2 sec for a two-man operation, and from 2.3 to 5 sec for a one-man operation. Exact fare systems were at the lower end of this range while procedures requiring drivers to give change and provide information were at the upper end. The dead times ranged from 1 to 7 sec with the presence and type of interlocking device being the main contributing factor to long dead times.

Kraft and Bergen reported on studies of U.S. bus loading and unloading rates (3). They studied both one- and two-door operations and used stepwise regression analysis to fit either sequential, interaction, or simultaneous models to the data. Their results should be interpreted with caution, however, because the data were collected such that "passenger service times were recorded from the moment the doors opened until the last passenger alighted from or boarded the vehicle." This is in contrast to other studies that start timing from the moment the vehicle stops and continues until the vehicle moves (or is ready to move). The data collection method employed by Kraft and Bergen (3) therefore means that dead times will be underestimated, especially in view of Cundill and Watts' (2) comments concerning door interlocking devices. In fact, many of Kraft and Bergen's (3) regression equations imply dead times of less than zero.

Bearing this limitation in mined, some of the overall conclusions of Kraft and Bergen (3) are worth noting:

1. Morning and evening peak period results are similar, but off-peak boarding and alighting rates are slower than peak period rates.
2. Exact fare systems save between 1.4 and 2.6 sec per passenger in boarding operations [this compares with a saving of 3 sec given by Cundill and Watts (2)].
3. Alighting rates were fairly constant within the range of 1.0 to 1.4 sec.

The only study in which alighting rates were found to be very different from 1.0 to 1.5 sec was by Nelson (5), in which he described the operation of a credit card fare collection system. In this system, fares were fixed according to the distance traveled, and required that a credit card be inserted into a validation machine at the beginning and end of the trip. In this study, both boarding and alighting rates were found to be approximately 4 sec per passenger. This study clearly demonstrates that it is the ticketing procedure that determines the boarding and alighting rate. The dependence on ticketing procedure is also clearly shown in boarding rates quoted by Grigg (6). He gives boarding rates of 1.5 to 2.5 sec for roving conductors and proof-of-payment systems, 3.0 to 5.0 sec for flat-fare one-man operation systems, and 3.5 to 8.0 sec for graduated and zone fares with one-man operation.

Few studies have examined the variability of boarding times. Jordan and Turnquist (7) stated that in their study of Chicago buses, the variance of the stopping times was constant (and equal to 8 sec^2) for all boarding numbers greater than 1 and up to 12. This contrasts with the statement by Cundill and Watts (2) that "the variance of stop time was found to increase with the number of persons handled." From a single distribution of stop times for one passenger boarding a two-doorway, one-man operation bus (2), it is possible to calculate that the coefficient of variation (COV) for a single boarding is approximately unity.

The meager published data on boarding time variability was supplemented by a study carried out on Melbourne trams (4). In addition to calculating the mean values of the boarding rates, this study also allowed investigation of the variance in boarding and alighting rates. The variances in boarding and alighting rates for boarding numbers up to 5 and alighting numbers up to 6 (beyond which sample sizes were too small to allow meaningful calculation of the variance) are shown in Figure 1. It appears that the data collected in this study would tend to reinforce the finding of Cundill and Watts (2) rather than that of Jordan and Turnquist (7) (i.e., variance increases with increasing numbers of boarders or alighters rather than remaining constant). To infer

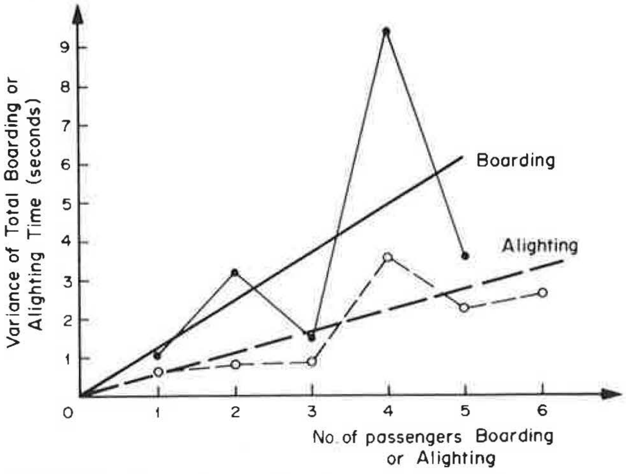

FIGURE 1 The variance of boarding and alighting times.

any more from Figure 1 concerning the form of a definite relationship would, however, be difficult without a specific behavioral hypothesis.

Consider, then, the proposition that successive boarding or alighting events are independent of each other. In this case, the variance of the boarding time for n boarders is equal to n times the variance in the boarding time for one boarder. If the variance in dead time is assumed to be zero, then the relationships shown in Figure 1 should be represented by straight lines passing through the origin. Least-squares estimates of these lines are overlaid in Figure 1 on the actual data points. While being far from a perfect fit, the assumption of independence between successive boardings or alightings does provide a useful working relationship in an attempt to describe the variability of boarding and alighting times. All that is needed to quantify this relationship is the coefficient of variation for single boarding and alighting events. From the lines of best fit shown in Figure 1, the coefficient of variation for a single boarding, given that the average boarding rate is 1.4 sec per passenger, is 0.8, while the coefficient of variation for a single alighting is 0.75. These values are in general agreement with the value of 1.0 derived from Cundill and Watts (2).

This review of boarding and alighting rate models, supplemented by some empirical observations, has served to provide some background to the analysis carried out in the remainder of this paper. In particular, it has given a feeling for the range of boarding and alighting rates likely to be encountered in practice, together with some possible values of the COVs. Obviously, more empirical observations are needed to fully quantify the boarding and alighting rate models for local conditions. In particular, the variation in boarding and alighting rates is a topic about which little is known (or, at least, has been published).

THE TRAMS PACKAGE

The TRAMS package is an event-update simulation model that simulates the movement of individual trams as they traverse a user-specified route. The model structure and characteristics have been described previously (see 8-10 and paper by Vandebona and Richardson elsewhere in this record) and will not be described in detail in this paper. Briefly, though, the model accepts inputs describing the route, vehicles, external environment, and passenger demand pattern over time and space. The model then simulates tram movements on the route for a specified time period, and outputs a wide array of route performance measures.

The simulation model operates by reference to a series of submodels that generate stochastic outputs for further use in the model. The major submodels handle the generation of:

- Departure time from terminus,
- Vehicle characteristics,
- Link travel time,
- Passenger demand patterns,
- Tram stop service times,
- Traffic signal phasing and timing, and
- Other turning traffic arrivals and departures.

The details of many of these submodels have been described elsewhere. In this paper, reference will only be made to two of these submodels (passenger demand patterns and tram stop service times), which are of greatest relevance to the current study.

Passenger Demand Patterns

The TRAMS program allows for variations in passenger demand along the route as well as time of day. The program requires the passenger origin-destination linkages to be identified in the form of an origin-destination matrix for a specified time period. Different origin-destination matrices can be input for different time periods of the simulation session. However, in the absence of origin-destination data, the program has the facility to synthesize such data from boarding and alighting information. Again, provision is allowed to incorporate variations with the time of the day.

The TRAMS package incorporates a pregeneration section that processes the previous data and produces a passenger list based on stochastic generations. This list contains the time of arrival and the desired destination for each passenger at each stop along the route. In some simulation experiments, it could be desirable to use a passenger list produced previously for the same network. Such a method would be especially useful for comparative studies of different system characteristics.

Therefore, there are three different ways in which the passenger demand can be introduced to the program. The passenger demand could be described by an origin-destination matrix, by passenger boarding and alighting vectors (in which case the program synthesizes the origin-destination matrix) or by an existing passenger list (in which case the pregeneration is no longer required). Once passengers have boarded a tram, their movements are recorded by means of a vehicle matrix that keeps track of the desired destinations and the seating status of all passengers currently on board. The program refers to this vehicle matrix to determine which passengers wish to alight at the next stop.

Tram Stop Service Time Submodel

The first task that this submodel performs is to check whether the tram actually does stop at the tram stop. If there is an alighting passenger, then the tram will always stop. If there are no alighting passengers but there are passengers wanting to board, then the tram will stop provided that the tram is not full; otherwise, the tram will proceed through the stop unless it is blocked by a previous tram that is waiting at the stop, or if the stop is at a traffic signal that is red.

Assuming that the tram will stop, the submodel then calculates the time needed to service boarding and alighting passengers. Although the number of alighters can be determined before the tram stops, it is not possible to exactly determine the total number of boarders until the tram leaves the stop because some passengers (the so-called "runners") will not arrive at the stop until after the tram has stopped and is engaged in loading passengers who are already waiting. In the study reported on in this paper, a simultaneous service time model is used to reflect the use of two-door trams on the route.

The final determinant of tram stop service times is the capacity of the tram itself. Obviously when the tram is full, no further passengers can board. The definition of "full," however, is somewhat subjective. Rather than apply a rigid definition of vehicle capacity, the boarding submodel compares the number of passengers waiting to board with the number of spaces left on the tram. If the number of boarders does not exceed the number of spaces by more than five, then all boarders will be allowed to board. This avoids the situation where only one or two people are left standing at the stop and is a reasonable approximation of the discretion shown by drivers and conductors. If, however, the difference is greater than five, then the tram will only accept boarders up to its official capacity before leaving the stop. This situation is more characteristic of heavy peak-hour loading situations. The capacity restraint affects the tram stop service time, however, only when boardings are the critical element in the service time process.

THE SIMULATION STUDY

The objective of the study was to examine the effect of different fare collection strategies on the tram performance along a route. Different fare collection strategies are reflected quantitatively in terms of different boarding rate parameters. It is assumed that no other factors (such as alighting rates and dead times) are affected by the changes in fare collection strategies. The changes are tested with reference to a specific route structure as described in the following paragraph.

Simulation Inputs

Rather than test the effect of fare collection strategies on a completely hypothetical route, the study reported herein was based on Melbourne Metropolitan Transit Authority tram route 75, which runs between East Burwood and the central business district. The route is on-street, approximately 18 km in length, contains 73 regular stops, and passes through 32 signalized intersections. While although the route used in this study is not identical in all respects to the East Burwood route, the use of the route as a basis ensures that there are realistic assumptions concerning stop spacing and the placement of tram stops relative to signalized intersections. In addition, passenger boarding and alighting distributions were based generally on observations of patronage during the morning peak period.

In addition to the general route description, a number of specific input parameters must be specified to enable the model to run. Some of the more important parameters, and the values used in this analysis are

1. Tram cruise speed = 50 kph
2. Acceleration rate = 1.25 m/sec ^{2}
3. Deceleration rate = 1.50 m/sec ^{2}
4. Passenger alighting rate = 1.0 sec/passenger
5. Alighting rate COV = 0.1
6. Boarding dead time = 4.5 sec
7. Alighting dead time = 4.5 sec
8. Boarding dead time COV = 0.1
9. Alighting dead time COV = 0.1
10. Tram capacity = 75
11. Tram seating capacity = 52
12. Simulation period = 7 a.m. to 9 a.m.
13. Average headway = 5 min
14. Number of simulation repetitions = 10.

In testing the effect of variations in boarding rate, the simulation was run for a range of average boarding rates and for a range of single-passenger-boarding COVs. Given the results of previous empirical observations described earlier in this paper, it was decided to test average boarding rates in the range of 1.0 to 8.0 sec per passenger. The selection of a range for the COV was more difficult because of the limited amount of information on this parameter. Given that the limited information available indicated a value in the vicinity of 1.0, it was decided to test for values on either side of this COV. At one extreme, the COV was set to zero (i.e., perfectly regular boarding) while at the other extreme, a high value of 4.0 was selected. Pending further empirical observation, it was felt that this range would cover the values likely to be encountered in practice. Within the range of average boarding rates and COVs, any fare-collection strategy for a two-door tram can be identified, ranging from proof-of-payment or two-man operation to one-man operation with the driver collecting graduated fares and giving change to passengers.

Simulation Results

The results of the simulation can be presented in terms of the effect on route productivity, and the effect on the level of service offered to passengers.

Route Productivity

To the operator, the productivity of the service will be reflected primarily in terms of the tram travel time along the route and the variability of this travel time. These measures will determine the number of trams required to maintain a specific frequency along the route. To the operator, costs or savings obtained by changes in fare-collection strategy must be offset against costs or savings experienced as a result of changes in the fleet numbers required to maintain a specified route frequency.

The route travel times obtained for different values of average boarding rate, and boarding rate COVs, are shown in Figure 2. As expected, route travel times increase as the average boarding time per passenger increases. Route travel times increase from 46 to 57 min as the boarding time per passenger changes from the lowest value tested (applicable to a two-man roving conductor operation or a one-man proof-of-payment operation) up to the highest value tested (applicable to a one-man operation with the driver collecting graduated fares and giving change). Assuming that the return trip is similarly affected, the change in route travel time is equivalent to a 20 percent reduction in productivity of the vehicles on that route. Thus, extra costs would be incurred in maintaining the service frequency on this route. Note that apart from one extreme case, the boarding rate coefficient of variation appears to have no effect on the average route travel time.

The extent to which route travel time variability is affected by changes in the boarding rate is shown in Figure 3. It should be noted that the variability referred to herein is the variability across individdual vehicles in a morning peak period. It can be seen that the variability of travel time rises as the boarding rate slows down. Slower boarding times therefore produce a slower and more variable service in terms of route travel time. Both these effects would need to be taken account of when assessing vehicle productivity on this route. In addition to the effect of average boarding rate on the variability of route travel time, there is also a small, statistically significant effect of the COV of boarding rate on the variability of travel time.

Passenger Level of Service

In addition to the changes in vehicle productivity described previously, the use of different fare-collection strategies will result in changes in the level of service offered to passengers. Figure 4 shows the changes in average passenger travel time

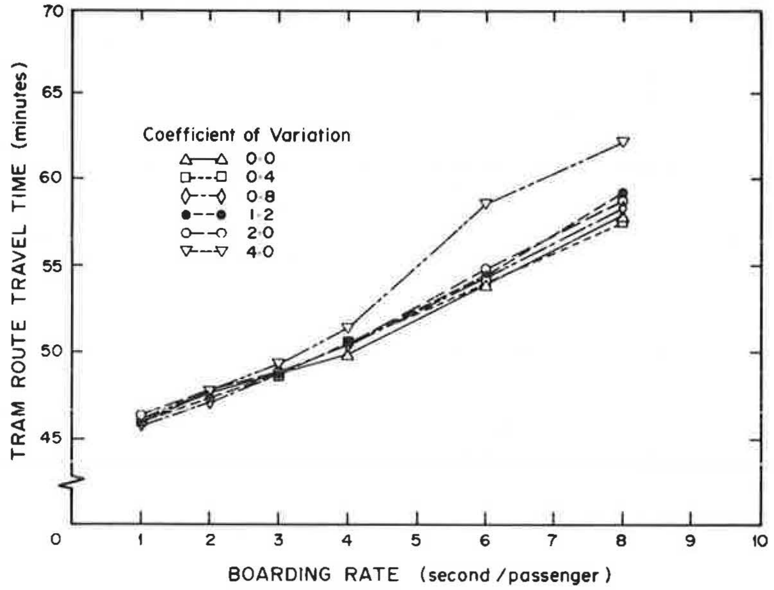

FIGURE 2 Average tram route travel time.

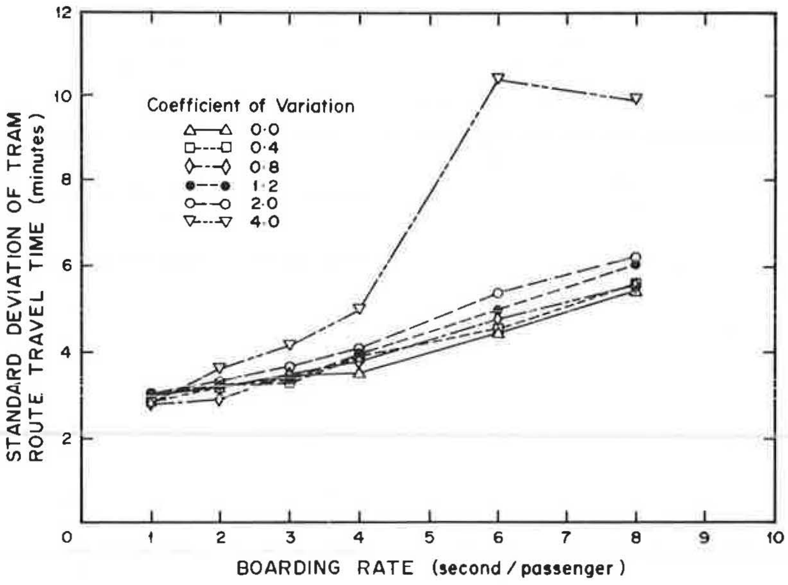

FIGURE 3 Standard deviation of tram route travel time.

as a function of the average and COV of the boarding rate. It can be seen that the average travel time increases substantially from 14 to 18 min as the boarding rate changes from 1 to 8 sec per passenger. The rate of change is near linear and is dependent on the total passenger boardings along the route. Routes with higher patronage would obviously be more affected by changes in the boarding rate. Once again, the average passenger travel time appears to be independent of the COV of boarding rate, except for combinations of high average boarding rates and high COVs. These combinations may, however, be unrealistic in practice, and so it may be concluded that passenger travel times are generally independent of the boarding rate COV.

One feature of public transport services that is often seen as being a measure of the reliability of the service is the tendency of vehicles to form bunches. Ideally, operators and passengers would prefer vehicles to maintain their initial separation over the entire length of the route. Breakdowns in service regularity are highlighted by the appearance of bunches. Figure 5 shows the change in average bunch size with changes in boarding rate. At the fastest boarding rate (1 sec/passenger), approximately 4 percent of the trams are in bunches. At the slowest boarding rate, approximately 20 percent of trams are in bunches. This increase in bunching is due to the slow boarding rates causing excessive service times that trigger off the formation of bunches. [For a full description of the bunching process, see Vandebona and Richardson (10).] Once again, increases in the COV have a small, significant effect, especially for combinations of high boarding rate and high COV where higher coefficients of variation result in an increased tendency for trams to form bunches.

The combination of slower and more irregular service results in an increase in the average passenger waiting time as shown in Figure 6. In chang-

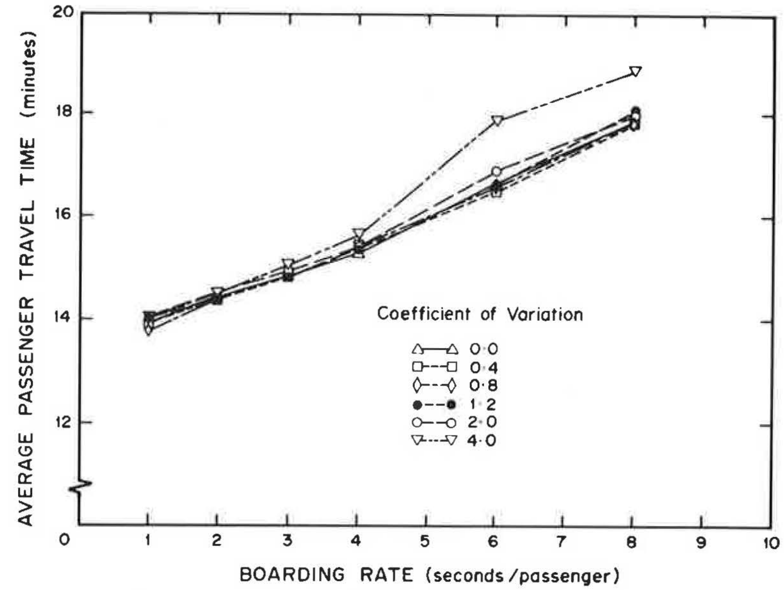

FIGURE 4 Average passenger travel time.

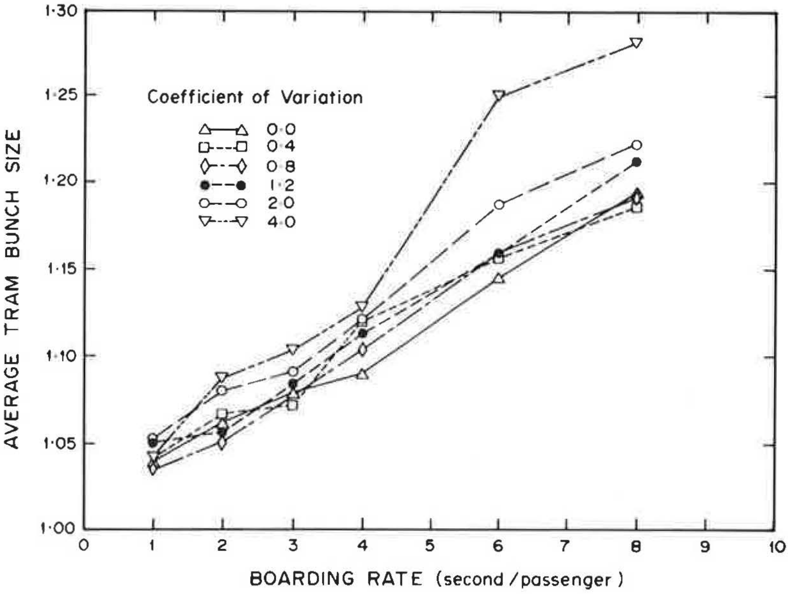

FIGURE 5 Average tram bunch size.

ing from the fastest to the slowest boarding rate, average waiting time changes from 3 to 4 min. Given that passengers are generally thought to value waiting time more highly than they value on-board travel time (by a factor of perhaps 2.5), this change represents an effective increase of 2.5 min compared to the change in average travel time of 4 min. With respect to waiting time, the COV of boarding rate has a small, significant effect for all average boarding rates except the quickest.

Another level-of-service measure, which is perhaps even more acutely perceived by passengers as a measure of waiting, is the probability of being left at a stop as a tram either departs the stop with a full load or else does not even stop because it is already full. While waiting time is measured on a continuous scale, being left at a stop is measured on a discontinuous scale; experiencing increased waiting time may not be perceived, but being left at a stop is unlikely not to be perceived (and complained about). The variation in this measure is shown in Figure 7. It can be seen that in going from the fastest to the slowest boarding rate, the probability of being left at a stop increases from 1 percent to approximately 7 percent. Put another way, for the regular commuter, it increases from once every 5 months (a rare event) to once every 3 weeks (a regular event). Once again, the COV has a small, statistically significant effect except at the quickest boarding rate.

The final level-of-service measure attempts to account for some aspects of passenger comfort. In particular, it measures passenger crowding in the vehicle in terms of the probability that passengers will be required to stand. As can be seen in Figure 8, the probability of standing increases as the boarding rate slows down. In fact, the probability of standing approximately doubles as the boarding

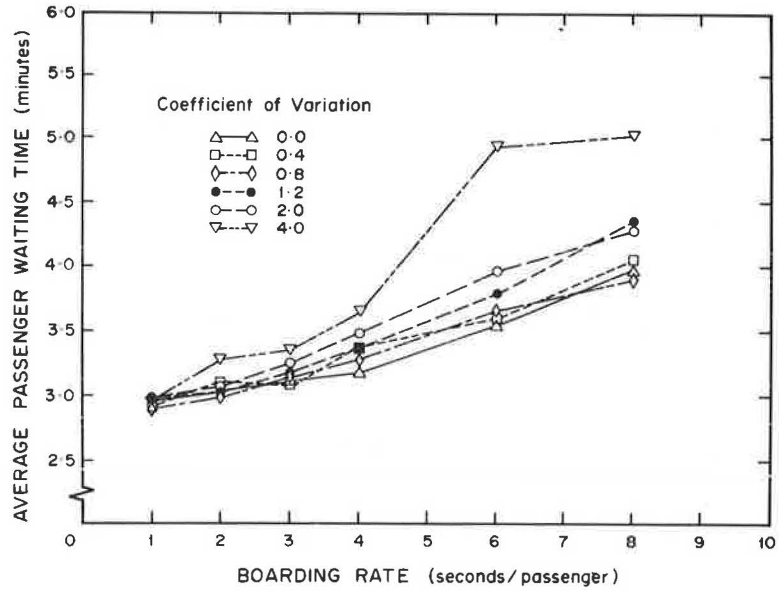

FIGURE 6 Average passenger waiting time.

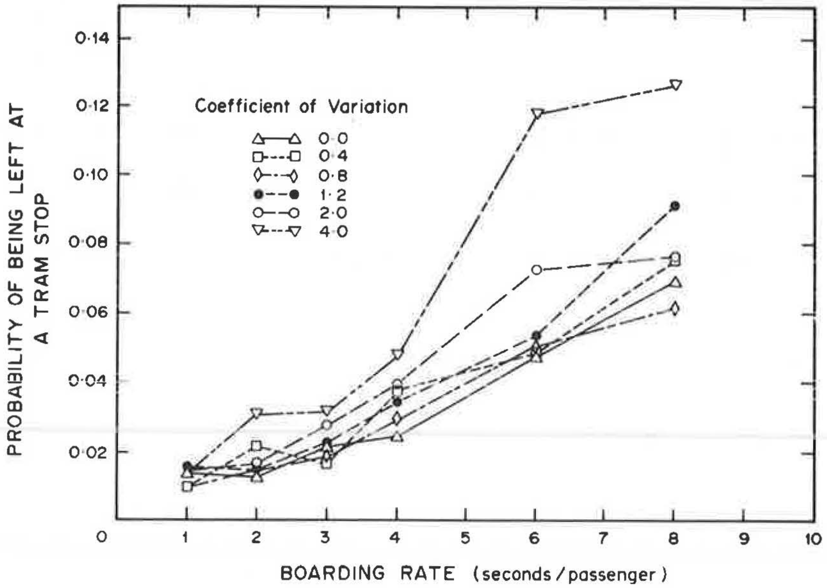

FIGURE 7 Probability of being left at a tram stop.

rate changes from fastest to slowest. Again, the COV has a relatively small, significant effect.

From the foregoing results, it can be seen that the changes in boarding rate have both primary and secondary effects. The primary effect, which is chiefly evident in the travel time results, is simply the result of spending longer times at stops loading passengers. As a result, the tram service slows down, as expected. The secondary effect, which is evident in the results for travel time variability, bunching, waiting time, and passenger crowding, is the result of trams departing from schedule because of the occasional long service time. This departure from schedule triggers the formation of bunches that cause several manifestations of irregular service. While although the coefficient of variation of the boarding rate has no effect on level-of-service measures exhibiting the primary effect, it is a contributing factor to variations in level-of-service measures exhibiting the secondary effect.

CONCLUSION

In this paper, the effect of different boarding rates on the productivity and level of service of a tram route has been demonstrated and the fact that slower boarding rates produce a slower and less reliable service along the route has been shown. The variability of boarding rates has no effect on route travel time but does contribute to greater unreliability in the level of service offered to passengers. The analysis reported in this paper is, however, only the first step in a complete investigation of the changes induced by a change in fare-collection strategy. As noted in Vandebona and Richardson (10), the complete public transport evaluation process

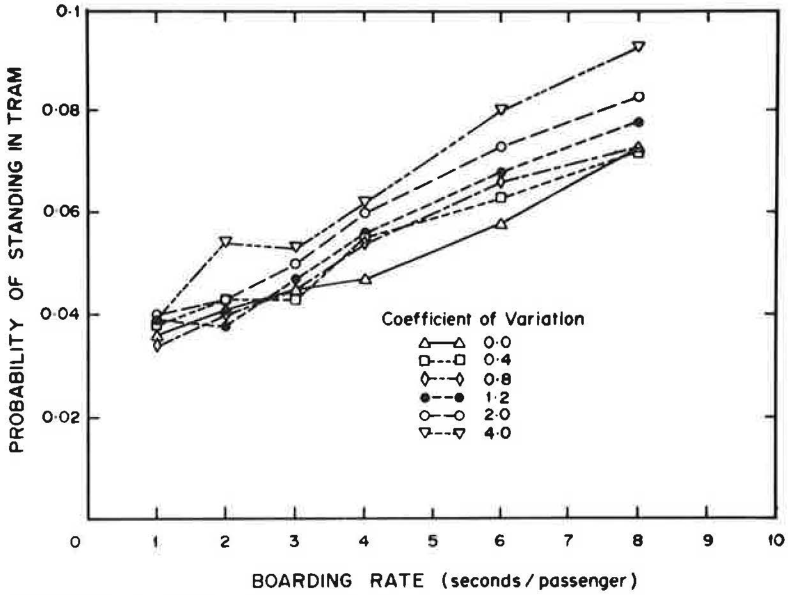

FIGURE 8 Probability of standing in the tram.

consists of three distinct modeling phases: (a) supply, (b) demand, and (c) cost. In this paper, only one of these phases--the supply model--has been described. Knowing that different fare-collection strategies have different boarding rates and that these, in turn, result in different route performance does not give the public transport manager enough information on which to base a decision on whether to change fare-collection strategies. In particular, he needs to know about three other factors.

First, the manager needs to know whether the changes in the level-of-service offered to passengers will be sufficiently large to affect usage along the route. If so, what will the effect be on revenue collected on that route? This question can be addressed by a demand model. Second, the manager needs to know the initial cost of implementing the changes in fare-collection strategy in terms of direct costs (staff and other costs) and variable and fixed overheads. Third, the manager needs to be able to cost the changes in productivity brought about by introduction of the new fare-collection strategy. Both these tasks can be addressed by means of a costing model (11). If the public transport manager wishes to go further and conduct an economic analysis, rather than the financial analysis outlined previously, then he needs further information concerning the value of level-of-service changes and the resource costs involved in providing the service.

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