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Rail Transit Planning and Rail Stations

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55 traffic flow, capacity, and measurements

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Contents

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Short-Term Impacts of a Suburban Rail Rapid Transit Station: Study Results for Silver Spring, Maryland

ROBERT M. WINICK AND STEVEN A. SMITH

Results of a before-and-after study for the Silver Spring station of the Washington, D.C., Metro rail rapid transit system are presented. The study focused on the short-term impacts on the Silver Spring business district of the initiation of rail service and coordinated changes in collector and community transit services. Findings are reported for several impact categories, including transit use, changes in travel habits, traffic and parking impacts, and the community's perceptions of Metro. There were significant initial increases in transit use in the station service area: about 100 percent for regional service and about 200 percent for local services. The percentage of transit work trips to Silver Spring increased from 10 to 13 percent. Approximately 40 percent of midday nonwork trips made by Silver Spring employees into the District of Columbia were made by Metro. Surveys at the station show that a significant proportion—approximately 60 percent—of Metro riders in the morning peak period get to the station by bus and another 16 percent walk. Parking became the most serious negative impact of the station; 1500 daily parkers were added to the parking supply in Silver Spring, which increased the peak-hour occupancy for long-term spaces from 80 to 92 percent. However, this was partly offset by increased use of transit to Silver Spring. Special attitudinal surveys of Silver Spring businesses and residents indicated that, in spite of short-term problems, the overall impact of the station was positive.

The first extension of the Metrorail rapid transit system into the Washington, D.C., suburbs has provided improved accessibility for people from that portion of the metropolitan area to downtown Washington. Just as importantly, it has enhanced transit access to the major regional activity center at its interim terminal, the business district of Silver Spring, Maryland. The main intent of this paper is to disseminate the results of an impact study conducted by the Montgomery County Planning Department of the Maryland-National Capital Park and Planning Commission as a subelement of the overall Metro before and after studies of the Metropolitan Washington Council of Governments (1).

STUDY FRAMEWORK

Geographic and Transportation Setting

The Silver Spring, Maryland, central business district (CBD) is located just beyond the "north corner" of the square that forms the boundary of the District of Columbia and about 1 mile south of the Capital Beltway (see Figure 1). The Silver Spring CBD is a major regional office and retail center that serves Montgomery County and parts of the neighboring District of Columbia and Prince Georges County. The CBD contains nearly 3.0 million ft^2 of office space, 1.7 million ft^2 of commercial space, and approximately 3600 residential units and has about 17 000 employees. It is served by three major arterial highways, commuter rail service on the Baltimore and Ohio Railroad, many Metrobus routes, and the Montgomery County Department of Transportation (DOT) innovative Ride-On minibus service.

In February 1978, the Metro "Red Line" was extended to the station at Silver Spring. It will serve as the terminal station until the line is extended to Glenmont, which is now scheduled to take place in mid-1986. The station itself is located alongside the railroad right-of-way and about 1200 ft away from the retail core. Bus feeder services were coordinated with the station opening (2). This involved the relocation of the previous bus terminal to the station area, the turnback of downtown-oriented routes, and expansion of Metrobus and Ride-On services. Other changes were made in transportation facilities, including several roadway improvements, increases in parking rates several months after the station opening, and conversion of the time duration for many parking meters.

Study Focus

The focus of this study has been on the impacts on the Silver Spring CBD associated with these initial changes in transit service, both those of the regional rail service and those of the collector and community transit service. Although the study was not directly concerned with regional travel from the Silver Spring area into the District of Columbia, secondary data of that type were available from the Washington Metropolitan Area Transit Authority (WMATA) and other sources and were analyzed in the study. The study framework was set up to examine not just the localized, as opposed to regional, impacts but also to concentrate on the short-term impacts. The intent was to provide a "snapshot" just before and just after these changes in transit service. This effort has been aimed partly at setting the stage for the monitoring of longer-term impacts of the Metro station and the overall Metro system in order to better relate to local comprehensive and land use planning efforts.

Data Sources and Survey Methods

Measuring the types of impacts that were of concern to Silver Spring required an extensive amount of new data collection as well as reliance on several sources of secondary data. Seven basic types of surveys were conducted for the study, five of which were conducted both before and after the station opening:

1. Establishment survey and employment census (before period only),
2. Travel surveys of people employed in Silver Spring,
3. Person-trip-generation studies,
4. Cordon traffic surveys,
5. Traffic counts at key intersections,
6. Parking studies, and
7. Perception and attitudinal studies (after period only).

Other secondary sources of data complemented the above data collection efforts. These included (a) a May 1978 WMATA rail survey, (b) other WMATA and Montgomery County DOT transit data, and (c) other county DOT traffic and parking data.

FINDINGS

The findings of the Silver Spring Metro before and after studies are presented in five categories: transit use, travel habits, traffic, parking, and perceptions of Metro.

Transit Use

As Figure 2 shows, the growth in average weekday transit use in the corridor from Silver Spring into the District of Columbia has been steady and dramatic. Within the first 10 months after the opening of the Silver Spring station, ridership approximately doubled over the previous bus-only riders. During the month of May 1978, when the after surveys were conducted, there were about 9500 average daily alightings at the Silver Spring station. By May 1979, ridership had increased to more than 15 000 alightings/day. It has since peaked (in the summer of 1979, during the gasoline shortage in the Washington area) and then declined slightly.

When rail rapid transit service was extended to Silver Spring, there was also a major expansion in the county-operated Ride-On system. The initial response was a tripling of ridership, from somewhat less than 4000 daily riders to 12 000 at the time of the after surveys. This represents travel not only to the Silver Spring CBD but also to other locations in the vicinity of Silver Spring and to the Takoma Park Metro station. It is estimated that about half of the initial Ride-On ridership was related to Metro access. Figure 3 compares the growth in Ride-On system ridership with the alightings at Silver Spring and shows a general correlation between the two transit services.

Travel Habits

The opening of the Silver Spring Metro station, accompanied by improvements in bus services, has brought about a number of major changes in the travel habits of persons going to and from the Silver Spring CBD. Accordingly, persons traveling to and from Silver Spring have been faced with new

Figure 1. Location of Silver Spring Metro station.

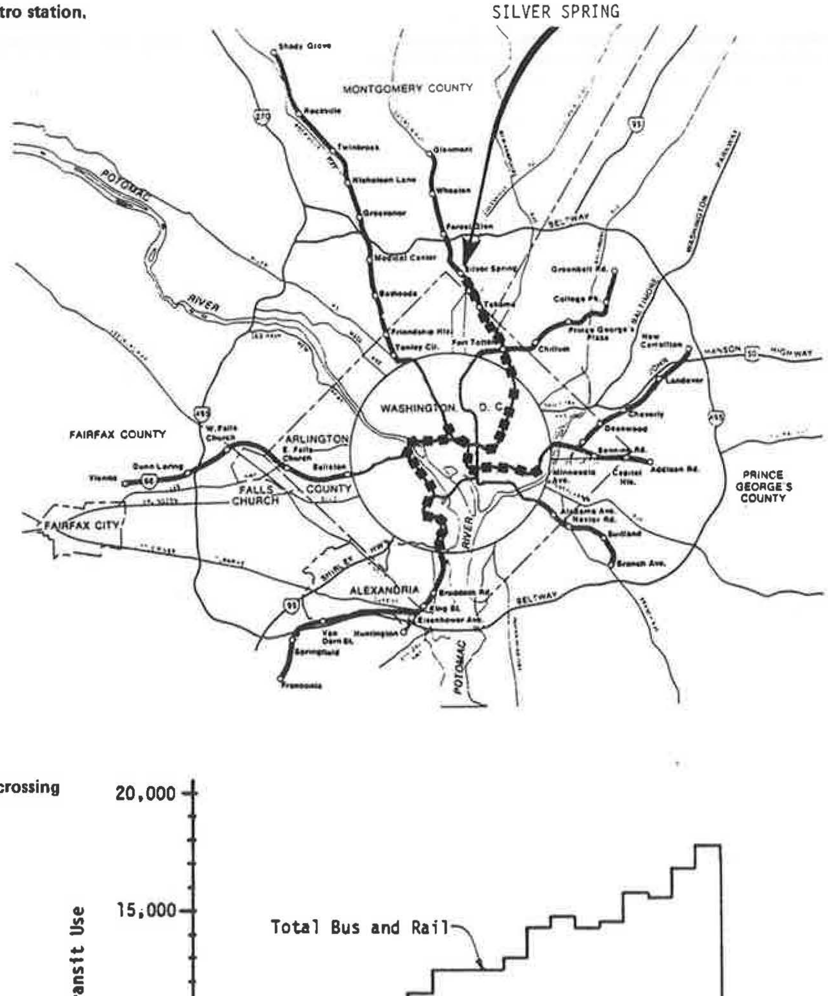
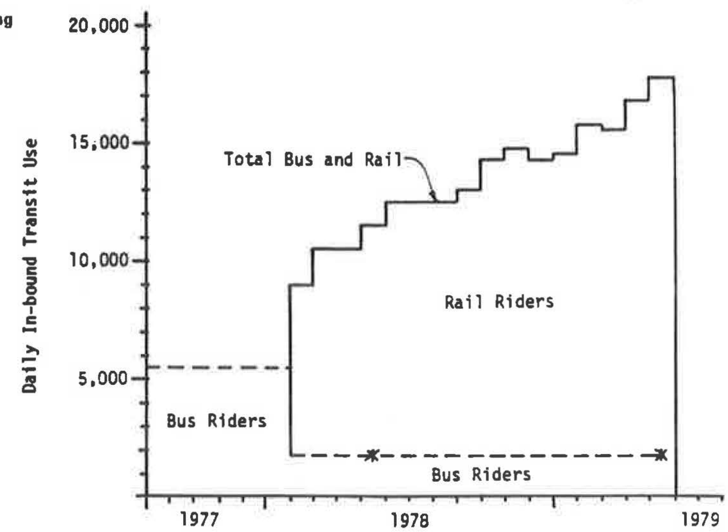


Figure 2. Daily in-bound transit users crossing District line from Silver Spring.



opportunities to change their habits of travel. These changes in travel habits were examined in the following categories of trips:

Type of Trip	Source of Data
Work trips to Silver Spring	Silver Spring employee surveys
Morning-peak-period trips from Silver Spring by Metro	WMATA rail survey
Nonwork trips by employees in Silver Spring	Employee surveys
Off-peak-period trips to and from Silver Spring via Metro	Rail surveys

Work Trips to Silver Spring

Work trips to Silver Spring include trips made by persons employed within the Silver Spring CBD boundary for the purpose of reporting to work. The table below gives data on the percentage of work trips by travel mode for employees in Silver Spring for both before and after periods (N = 2905 and 2436 for before and after, respectively):

Travel Mode	Before (%)	After (%)
Automobile		
Driver	74.9	71.2
Passenger	7.8	8.3
Dropped off	2.6	2.8
Metrobus	6.6	4.6
Ride-On	2.3	4.9
Commuter rail	1.4	1.5
Metro	0	2.0
Walk or bicycle	3.9	4.6
Taxi	0.3	0.1

For the after period, percentages for automobile driver, Ride-On, and Metro are significant at the 95 percent confidence level.

The number of employees who drove their cars to work decreased by almost 4 percent after Metro opened. Some of this reduction can be attributed to automobile trips diverted to Metro, but the major factor is more likely the improvement in Ride-On service. This shift indicates a reduction of approximately 600 spaces in parking demand by employees. Total transit ridership for work trips to Silver Spring increased from 10.3 percent in the before period to 13.0 percent in the after period. Metrobus ridership declined by 2 percent. It is evident from data discussed below in relation to jurisdiction of residence that this reduction was caused both by persons in the District diverting to Metro and by residents in the Silver Spring vicinity diverting to Ride-On. Ride-On is now serving 5 percent of the employee work trips. Trips by Metro riders constituted 2 percent of work trips to Silver Spring in the after period. This is equivalent to approximately 700 one-way work trips on Metro each day by Silver Spring employees.

Mode of Travel by Jurisdiction of Residence

Table 1 gives work-trip travel modes by jurisdiction of residence. Several items are of interest in this table. First, the percentages of automobile drivers are substantially lower for Silver Spring and District of Columbia residents. Of Silver Spring residents within the Capital Beltway (within 2-3 miles of the Silver Spring CBD), more than 20 percent preferred walking to work, which points up the value of mixed office and residential land development in what is normally considered a suburban setting. In addition, Ride-On service is readily available to these residents and was used to get to work by 14 percent of the employees in this category, an increase of 5 percent over the period prior to Metro route expansion.

The other very noticeable change is the Metro ridership among residents of the District of Columbia who work in Silver Spring, almost 15 percent of whom were found to take Metro once it opened. From Table 1, it would appear that most of these subway riders previously rode Metrobus. Subway ridership for Virginia residents working in Silver Spring was more than 9 percent, but the mode shift for this group appears to be primarily from the automobile.

Prior Travel Mode of Transit Users

In the after-period survey of Silver Spring employees, persons who took public transit to work were asked how they made the trip before the Silver Spring station opened. Table 2 gives the responses to this question. Almost two-thirds of those who rode Metrobus to work in Silver Spring also used Metrobus before the Metro station opened. More than 20 percent of Metrobus riders had diverted from the automobile. Approximately one-third of the employees who took Ride-On also took Ride-On before Metro. Among those using the Ride-On service, about 25 percent were diverted from automobiles and 25 percent from Metrobus. Almost half of the respondents who used Metrorail had previously used the automobile.

Morning-Peak-Period Trips from Silver Spring by Metro

Substantial information on commuter trips by Metro from Silver Spring into the District was obtained from the WMATA survey of Metro passengers. These include trips largely made by persons residing around and north of the Silver Spring Metro station. The Takoma Park station, which is located about 1 mile south of Silver Spring, serves residents to the south.

Four aspects of these trips are described in the WMATA survey: (a) mode of access, (b) alternate mode of travel, (c) effect on automobile travel, and (d) work trips by Silver Spring residents.

Mode of Access

The table below indicates how those commuting from Silver Spring into the District got to the Silver Spring Metro station in the morning peak period (N = 1000):

Access Mode	Percentage
Metrobus	31.2
Ride-On	24.8
Automobile	
Driver	14.5
Passenger	12.0
Walk	16.2
Other	1.3

Fifty-six percent of the riders came by bus, and there were approximately as many people walking to the station as there were driving.

A comparison of mode-of-access statistics at somewhat comparable suburban rail rapid transit stations on the Toronto, San Francisco, and Philadelphia systems shows interesting results. The Silver Spring station is operating more like the terminal stations in Toronto, where there is heavy

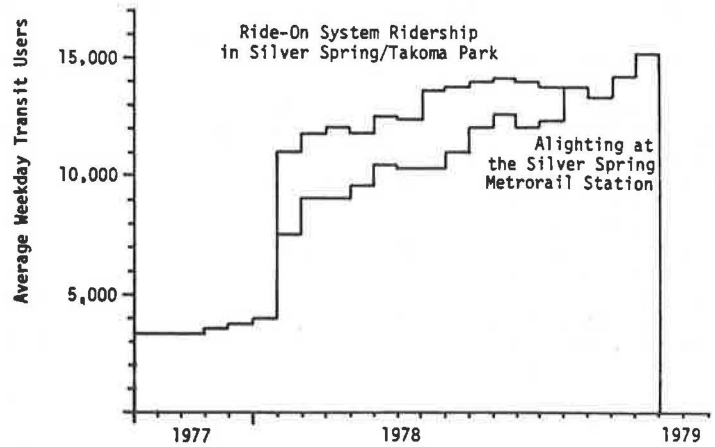


Figure 3. Comparison of Ride-On and Metro ridership at Silver Spring station.

Table 1. Work-trip travel mode by jurisdiction of residence.

	Silver Spring Within Beltway (%)		Elsewhere in Montgomery County (%)		Prince George's County (%)		Elsewhere in Maryland (%)		District of Columbia (%)		Virginia (%)	
Category	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Automobile												
Driver	52.9	48.7	81.1	75.5	84.2	84.2	78.9	76.2	57.4	56.5	87.4	76.6
Passenger	7.7	7.0	6.5	8.4	7.2	6.6	11.1	14.3	8.1	3.3	7.8	9.6
Dropped off	2.4	4.5	2.7	1.4	2.7	2.7	2.3	3.7	3.4	6.6	0.4	0.9
Metrobus	6.0	2.6	5.1	5.8	4.2	3.1	2.9	1.6	27.0	15.2	3.8	1.9
Ride-On	9.0	13.8	0.8	4.4	1.1	2.1	0.6	0.3	0.4	1.9	0	0
Commuter rail	0.1	0	2.5	2.9	0.3	0	3.1	1.5	0	0.4	0	0.5
Metro	0	0.2	0	0.2	0	0.8	0	0.8	0	14.9	0	9.3
Walk or bicycle	20.2	21.7	0.4	1.3	0	0.3	0	0	0.6	0.2	0	0
Taxi	1.2	0.8	0.2	0	0	0	0	0	0.4	0	0	0
Other	0.5	0.7	0.6	0.1	0.4	0.3	1.1	0.3	2.1	0.9	0.7	1.1
Proportion of all work trips	18.4	18.4	37.6	38.6	18.9	18.6	10.2	10.6	8.2	6.9	6.7	6.9

Table 2. Prior travel mode for transit work trips to Silver Spring.

	Current Mode (%)		
Prior Mode	Metrobus[a]	Ride-On[b]	Metro[c]
Automobile	21.6	24.5	47.3
Metrobus	65.7	24.2	31.0
Ride-On	0.8	36.8	2.5
Commuter rail	0.7	1.5	0
Walk or bicycle	0	1.6	0
Taxi	0	2.2	0
Other	0.7	1.4	0
Did not work in Silver Spring before	10.4	7.7	19.1

[a]N = 106. [b]N = 113. [c]N = 46.

reliance on bus as a mode of access, than like comparable stations on the Bay Area Rapid Transit (BART) System, where commuters rely on both bus and automobile, or stations on the Lindenwold Line, where commuters rely primarily on the automobile.

Alternate Mode of Travel

The Metro surveys conducted by WMATA asked respondents to state what mode of travel they would have used for their trip had there been no subway. The following table gives alternate mode of travel for persons making morning-peak-period Metrorail trips from Silver Spring (N = 1000):

Alternate Mode	Percentage
Metrobus	53.7
Automobile	
Driver	32.0
Passenger	5.6
Taxi	0.9
Walk	0
Other	6.3
No trip	1.5

More than 53 percent would have taken Metrobus, and almost 38 percent would have driven or ridden in a car.

Effect on Automobile Travel

The percentage of respondents designating "automobile driver" as their alternate mode in the table above indicates 1900 fewer automobiles in the corridor south of the station in the morning peak period. Between 7:00 and 8:00 a.m., a decrease of approximately 900 automobiles is indicated. Given these results, it would be expected that traffic volumes would be noticeably reduced on some of these roadways south of the Metro station. A comparison between these results and traffic data is made later in this paper.

Work Trips by Metro for Silver Spring Residents

Several other interesting findings were available from a telephone survey of 200 residents who live in or immediately outside the Silver Spring CBD. Ten percent of the persons interviewed used Metro to get to work five days a week. Approximately 18 percent had used Metro at least once to get to work. Of the 200 residents interviewed, 23 percent reported that their place of work was within walking distance of a downtown Metro station. Approximately half of these were consistently using Metro to get to work.

Nonwork Trips by Silver Spring Employees

The effect of Metro on the midday travel habits of people employed in Silver Spring is discussed below. Of particular interest is the influence of accessibility improvements on mode choice.

Mode of Travel

Table 3 gives data on the mode of travel for midday, nonwork trips by Silver Spring employees, categorized by one of three destination groups: (a) the Silver Spring CBD, (b) the District of Columbia, and (c) other destinations, including Montgomery County outside the CBD, Prince Georges County, Northern Virginia, and regions outside the metropolitan area. Clearly, trips within the Silver Spring CBD are dominated by the walk mode. The larger number of walk trips in the period after the opening of the Metro station is attributable to the seasonal difference in the before and after periods. Trips to destinations other than the CBD and the District are heavily automobile oriented. The subway trips to other destinations indicated in Table 3 are primarily trips to Northern Virginia.

The impact of Metro is identified primarily in those data in Table 3 that show travel modes to destinations within the District. The after data indicate that approximately 40 percent of midday, nonwork trips made by Silver Spring employees into the District are now being made by Metro.

Alternate Mode of Travel

In the employee travel survey, Silver Spring employees who used Metro for at least one midday trip were asked what means of travel they would have used and/or what location they would have gone to had Metro not been available. The responses are summarized below:

	Trips	
Alternative	Number	Percent
Would go to same place		
But use car	510	73.5
But use bus	101	14.6
But use taxi	13	1.9
Would go to Silver Spring CBD instead	35	5.0
Would not go at all	35	5.0

Of those employees who made midday trips by Metro, the majority would have used a car to make the trip had Metro not been available. Some trips would have been diverted to bus, and a few would have been made by taxi. A relatively small number of Metro trips (35 trips/day) would have been diverted to the Silver Spring CBD had Metro not been available. This is a strong indication that Metro is not siphoning off from the District business generated by Silver Spring employees. The times and costs associated with trips from Silver Spring to downtown are apparently too great to make these trips very attractive when other destinations are available. However, other data also indicate that Metro is not attracting business-generating trips to Silver Spring.

Off-Peak-Period Trips by Metro to and from Silver Spring

Data on off-peak trips by Metro to and from Silver Spring are available from the WMATA Metro surveys. The majority of these trips are nonwork trips, but some work trips are included.

The following table gives modes of access to the Silver Spring Metro station for the off-peak period (9:00 a.m. to 3:00 p.m.) (N = approximately 400):

Access Mode	Percentage
Metrobus	16.4
Ride-On	14.7
Automobile	
Driver	22.4
Passenger	16.6
Walk	27.4
Other	2.4

In comparison with modes of access during the morning peak period (almost all work trips), off-peak-period modes of access are much more walk oriented and much less transit oriented.

The table below gives the alternate modes of travel that would have been taken for Metro trips from Silver Spring in the off-peak period had there been no subway:

Travel Mode	Percentage
Metrobus	34.8
Automobile	
Driver	43.0
Passenger	6.2
Taxi	3.0
Walk	0.1
Other	2.3
No trip	10.6

Almost 80 percent of the trips would have been made by either automobile or Metrobus (slightly more than half by automobile). A comparison with previously cited data on morning-peak-period trips from Silver Spring indicates a higher percentage for the automobile as the alternate mode for the off-peak period and a lower percentage for Metrobus.

Traffic Impacts

Extensive studies were conducted on the impact of Metro on traffic volumes in Silver Spring and the District of Columbia to the south. Of the impacts examined, traffic was the most difficult about which to draw conclusions because of substantial day-to-day variability in volumes.

District of Columbia Traffic Volumes

Data on traffic volumes in the District indicate slight decreases in volume on Georgia Avenue but increases on 16th Street. One possible explanation for the increase on 16th Street is that many of the buses terminate their runs at the Metro station rather than continuing into the District and thus provide additional roadway capacity for automobiles. However, it is difficult to judge the effect of Metro on traffic congestion from traffic-volume data alone. This result is similar to that obtained in the BART impact study, which was unable to detect any changes in traffic volume fostered by the BART System except for a slight, temporary decrease on the Oakland Bay Bridge (3).

It is significant to note here that the District of Columbia recently converted 13th Street, which

Table 3. Travel mode for midday nonwork trips by Silver Spring employees to selected destinations.

Travel Mode	Trips to Silver Spring CBD		Trips to District of Columbia		Trips to Other Destinations	
	Before[a]	After[b]	Before[c]	After[d]	Before[e]	After[f]
Walk	7500	10 100	100	130	190	510
Automobile						
Driver	2500	2 100	910	650	5230	4850
Passenger	380	270	100	70	520	570
Metrobus	140	70	130	70	70	140
Ride-On	50	100	10	50	70	140
Taxi	40	40	10	10	50	50
Free shuttle	10	0	20	0	170	0
Metro	0	0	0	570	0	150
Other	40	50	30	10	50	100

[a]Population = 10 660; N = 1840.
[b]Population = 12 770; N = 1850.
[c]Population = 1350; N = 230.
[d]Population = 1560; N = 230.
[e]Population = 6340; N = 1100.
[f]Population = 6510; N = 940.

Table 4. Summary of parking data for county-operated facilities.

Item	Long-Term Parking		Short-Term Parking	
	Before	After	Before	After
Capacity	4203	4402	2782	2687
Daily parkers	5343	5894	8970	9122
Turnover (vehicles/space)	1.27	1.34	3.23	3.39
Average duration (h)	5.71	6.21	2.17	2.12
Occupancy (percentage of capacity)				
8:00 a.m.-6:00 p.m.	65	82	64	72
Peak hour	80	92	82	89

Table 5. Net impact of transportation changes on parking in county facilities.

Category	Number of Daily Parkers
Parkers added	
Metro	900
Other (shopping, etc.)	100
Silver Spring employees who formerly drove a car downtown in midday, now taking Metro and leaving car in Silver Spring	200
Subtotal	1200
Parkers subtracted (former car drivers)	
Using Metrorail	200
Using Metrobus	100
Using Ride-On	200
Subtotal	500
Total increase	700

parallels the Metro line, back to two-way operation, at least partly in response to the opening of the Silver Spring Metro station.

Traffic in the Station Area

In the area around the station itself, only slight increases in congestion appeared to take place. This was essentially verified in the after survey of Silver Spring employees when those driving automobiles to work were asked whether it now took them more time, less time, or about the same time to drive to work. Most employees driving cars to work (76.4 percent) did not perceive any difference in the travel time required before and after Metro. Approximately 16 percent of automobile drivers felt that they now took more time to get to work, and 7 percent felt that they took less time.

Parking Impacts

Parking in Silver Spring proved to be the most noticeable of the short-term impacts brought on by the opening of the Silver Spring Metro station. The mode-of-access data indicated that in May 1978 approximately 1450 vehicles parked in Silver Spring daily for the purpose of riding Metro.

Parking supply did not change significantly between the before and after periods. Approximately 6200 off-street county-operated spaces, 850 on-street spaces, 800 commercial spaces, and 5600 other privately owned spaces were available.

County-Operated Facilities

Parking accumulation data present the best overall view of the impact of Metro. Table 4, derived from data of the Division of Parking, Montgomery County DOT, gives the approximate number of vehicles using county-operated facilities in the before and after periods. The before data were obtained in the fall of 1977 and the after data in the spring of 1978. The implication of Table 4 is clear--namely, that Metro significantly increased parking occupancies in Silver Spring. The number of daily parkers increased by 550 vehicles (10 percent) for long-term spaces and 150 vehicles (2 percent) for short-term spaces. Peak-hour occupancy, a key indicator of parking availability, increased by 200 vehicles (12 percent) for long-term spaces and 100 vehicles (7 percent) for short-term facilities. The most heavily affected area was the parking sector adjacent to the Metro station, where peak-hour occupancies increased from 50 percent before to 100 percent after the opening of the station. There were acute parking shortages throughout the northern part of the Silver Spring CBD, where employment densities are highest. However, the effect would have been much worse had there not been significant improvements in bus service to Silver Spring.

Residential Areas

Since the fringes of Silver Spring contain residential areas that are close to major traffic generators, they are prime candidates for absorbing the pressures of parking shortages and the cost of parking in the CBD. The study indicated that approximately 400 additional vehicles were parking in residential areas after the Metro station opened. Personal interviews with people who were parking in selected residential areas that were most convenient to Metro indicated that approximately 25 percent (or about 100 vehicles) were parking to ride Metro. An additional 50 such vehicles may have parked in residential areas outside the times surveyed, for a daily total of 150 Metro parkers.

Perhaps more significant than Metro riders parking in residential areas is their parking in the CBD, thus displacing parking spaces otherwise available to employees and visitors, who must then park in the residential areas. It is estimated that another 100 vehicles parked in the residential areas are in this category. Thus, the total effect of Metro on residential parking was to create 200-250 new parkers in residential areas. The remaining 200 additional vehicles of the total 400-vehicle increase would probably have parked in the area, because of seasonal factors, even if the Metro station had not been opened.

Summary

As a summary of parking impacts, an effort was made to identify where the new Metro parkers were absorbed into the CBD and the residential area around it. The 1450 daily parkers are estimated to have been absorbed as follows:

Type of Facility	Number of Parkers
County	900
Private pay	50
Private free (legal and illegal) inside CBD	200
Residential on-street parking	150
WMATA kiss-and-ride lot, midday parking	150
Total	1450

An estimate was also made of the factors contributing to changes in parking in the county-operated facilities. Table 5 indicates that parking impacts on county facilities could have been even more severe had the significant shifts from automobile to transit of people destined to Silver Spring not occurred.

Perceived Impact of Metro

A summary of perceptions of the Silver Spring Metro station among business managers and residents in Silver Spring is reported below. Other groups were sampled but are not reported on here.

Silver Spring Businesses

A survey of 99 businesses was conducted during the after period of the project. A number of specific questions were asked, but only the overall perception of Metro is reported here.

When asked whether they thought that the effect of Metro was positive or negative for their business, businesses responded as follows:

Effect	Response (%)
Positive	61
Negative	13
Neither	24
Too soon to tell	2

By a ratio of nearly 5:1, businesses felt that, overall, Metro was a positive feature in Silver Spring.

Silver Spring Residents

A telephone survey of 200 residents in and around the Silver Spring CBD was also conducted. When asked if the Metro station had had a positive or negative effect on them as individuals, residents replied as follows (again, only the overall perception is cited):

Effect	Response (%)
Positive	47
Negative	12
None	24
Don't know of any	17

Positive responses outnumber negative responses by a 4:1 ratio, which indicates favorable initial impressions of Metro by residents.

SUMMARY OF RESULTS

The first extension of the Washington, D.C., Metro system into the suburbs and associated changes in local transit service have been studied with regard to their short-term impacts in the vicinity of the interim terminal at Silver Spring. Some of the more noteworthy of these impacts can be summarized as follows:

1. Transit use in the corridor between Silver Spring and downtown Washington doubled when the Silver Spring station opened and has doubled again since that time. Ridership on local transit service to Silver Spring and its vicinity has also increased significantly.
2. Observation of the travel habits of people employed in Silver Spring showed an increased reliance on transit. The percentage of work trips by transit increased from 10 to 13 percent. Almost half of the workers going to Silver Spring on Metrorail were previously automobile users. Data on nonwork trips by people who work in Silver Spring indicate that approximately 40 percent of those traveling into the District of Columbia are now using Metrorail and that about 75 percent of these are being diverted from automobile travel.
3. Approximately 60 percent of Metrorail commuters going from Silver Spring into the District during the morning peak period are getting to the Silver Spring station by bus; the remainder are almost equally divided among automobile drivers, automobile passengers, and walkers. If there had been no Metro, almost 40 percent of these trips would have been made by automobile. Indications are that Metro is capturing almost 50 percent of Silver Spring residents who live within half a mile of the station and have convenient walk access to their place of work from a downtown Metro station.
4. As expected from impact studies of other rail systems, effects on traffic were the most difficult to examine. Although the data indicate an initial peak-period reduction of about 2000 vehicles in the radial corridor between Silver Spring and downtown Washington, that reduction was divided among several arterials. There were slight increases in congestion in the vicinity of the station.
5. Parking in Silver Spring proved to be the most noticeable of the short-term impacts. It was brought about by the addition of about 1500 daily parkers in Silver Spring in the initial months of the station opening. However, the net effect on Silver Spring was about half that number of parkers, primarily because many Silver Spring employees switched to transit, making more spaces available for Metro users.
6. Attitudinal studies of the impacts perceived by businesses and residents of Silver Spring were conducted. By a ratio of almost 5:1, businesses felt that Metro was an overall positive feature in Silver Spring. The benefits appeared to relate primarily to improved access and the primary problem to be parking. For nearby residents, positive responses outnumbered negative responses by a 4:1 ratio.

ACKNOWLEDGMENT

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Philadelphia Center City Commuter Railroad Connection

E. L. TENNYSON

The city of Philadelphia has undertaken major construction to connect two separate commuter railroad systems in Center City to offer ubiquitous access to commuters. The rationale of such great investment in so small an area is explored. The basic theoretical justification is determined by the benefit/cost ratio, but physical impacts on passengers and service providers are also analyzed. Time saved is not evaluated in dollars. Commuter time savings produce no cash dollars to amortize costs but do generate more revenue and less expense, the net effect of which is favorable. The obvious direct advantages are not sufficient in themselves to fully justify the investment. The greatest single positive factor is the revitalization of the Philadelphia central business district east of City Hall. This has already begun and is being coordinated with project construction. The city is expected to benefit by more than $20 million/year in real estate and wage tax increases. Highway traffic will benefit from reduced congestion. Numerical values have been refined by various analysts over a period of 20 years. Data are based on final engineering plans, regional planning studies, and the author's work on the subject. To date, most of the actual construction bids have been near or below estimates, inflation notwithstanding. Double-digit inflation may change this, but 90 percent of the contracts have now been let. The strategic importance of careful operational implementation in achieving the best results is also analyzed.

The impact of improved transportation facilities on urban and metropolitan development is generally recognized to be considerable, for better or for worse, depending on many factors, including citizens' views concerning what is desirable and undesirable. Older cities are losing their manufacturing industry and associated employment, along with their higher-rated residential properties. Their tax base has not been increasing in parallel with the economy nor with inflation. The adverse economic effect of this is well known.

The city of Philadelphia has for many years looked to its rail transportation system to generate positive, private economic activity that will sustain and expand employment and the tax base. The attraction of riders to that system was and is necessary to bring sufficient activity to the central business district (CBD) without the choking congestion and air pollution that would result from greater individual travel by private vehicles. Regional planning studies have determined that in Philadelphia well over half of CBD trips are made by public transportation and that most of the choice riders use the rail facilities (1, p. 58).

Philadelphia's rail rapid transit system has two basic perpendicular main lines that intersect under City Hall in the center of the CBD. These two lines serve more than 300 000 person trips/weekday in the older areas of the city where income and population have declined as the more affluent and the decision makers have located in new housing farther out. There are healthy redevelopment activities in Center City, but they do not yet outweigh the losses.

Although the two subway lines are heavily traveled and efficiently run, they do not serve enough of the geographic area to shape further development. The service areas of these two lines cover an area of approximately 200 km^2 (75 $miles^2$) that has a population of 1 million (see Figure 1). The metropolitan area, however, covers 3150 km^2 (1200 $miles^2$) and has a population of 4 million. The Philadelphia suburbs have a reported density of more than 1500 people/km^2 (4000 people/$mile^2$). The city density is 6100 people/km^2 (15 000 people/$mile^2$), which is about the same as other large cities, New York excepted.

It is not economically prudent or financially possible to extend rail rapid transit lines over much of the area beyond that of highest density. Although voter support and court approval were obtained for a 9.6-km (6-mile) northeast extension of the Broad Street subway into newer areas of the city, this extension has not progressed beyond the final engineering work (2, p. 409).

Bus service has not been sufficiently attractive to hold many choice riders, and more riders now have a choice, particularly in the larger, lower-density areas surrounding the city. Bus riding in Philadelphia has declined dramatically since 1947, as it has in other cities, and less than one-third of the former ridership remains [see Figure 2 (3,4)]. A faster, more reliable, more economical, and more comfortable method of moving people beyond the rapid transit lines is essential. Exclusive busways are neither available nor feasible in this area because of the lack of low-cost right-of-way opportunity, the lack of central terminal capacity, and the labor intensity.

Philadelphia has one of the most extensive suburban commuter or regional rail systems on the North American continent. The system has 356 km (220 miles) of passenger right-of-way and an additional 181 km (112 miles) of route that extends beyond the suburban area into the adjacent but smaller metropolitan areas of Allentown-Bethlehem and Reading (see Figure 3). The latter area produces almost 120 000 rail commuter trips/weekday. This represents only 40 percent of rapid transit volume but almost the entire rapid transit work load in passenger kilometers [2.4 million passenger-km/weekday (1.5 million passenger miles/weekday)]. Each of the two systems has about 400 rail cars in service, excluding shopping margin and spares.

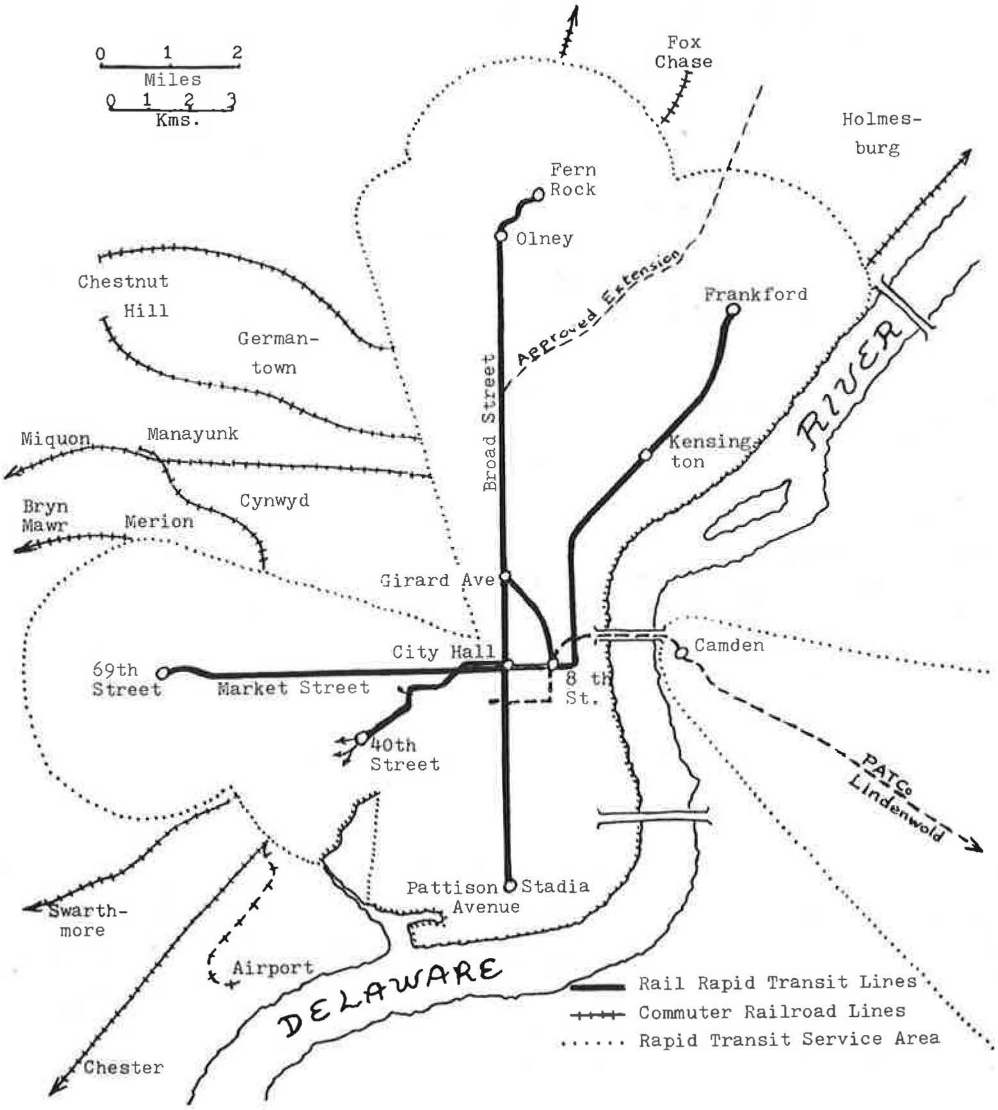
Just as it is infeasible to serve the dispersed suburbs with rapid transit, it is infeasible to serve the highest-density areas with commuter rail. It should be noted that, both in Philadelphia and throughout the country, commuter rail is carrying an increasing percentage of the urban transit work load [see Figure 4 (3,4)].

CENTER CITY COMMUTER RAILROAD CONNECTION

Philadelphia's two rail rapid transit lines operate through Center City from north to south and from east to west, offering linked trips (transfer connections) within the more densely populated area at minimal cost, time loss, and transfer delay. The commuter railroads, in contrast, are in two separate and distinct systems: the Philadelphia Division and the Reading District of the Consolidated Rail Corporation (Conrail). A commuter rail passenger cannot ride through the center of the city from one side to the other. A transfer involves considerable time loss and the added inconvenience of a 0.5-km (0.33-mile) walk or a local transit ride between the separate rail stations (see Figure 5).

For many decades, the retail shopping center of the city has been at Eighth and Market Streets, six blocks east of City Hall. Three subway systems intersect here for this reason, and Reading District commuter trains are only three blocks away. One of

Figure 1. Philadelphia rail rapid transit service area.



the subway systems is only a shuttle (Ridge Avenue), and another was little used from the early 1950s to 1968 while it awaited extension into the New Jersey suburbs, where it now terminates at Lindenwold, 21 km (13 miles) to the east.

After the conversion in 1956 of the Pennsylvania Railroad viaduct (the "Chinese Wall") west of City Hall into a multiple-building, high-rise office center (Penn Center), the concentration of downtown activity shifted to the west of City Hall, where access was available by way of three busy subway systems and the dominant commuter railroad. As a result, commercial viability east of City Hall declined as millions of square meters of new office space developed west of City Hall to take advantage of the volume of weekday rail passengers: 477 000 as opposed to only 292 000 east of City Hall (221 000 are dual counted because of dual access).

Data given in Table 1 on average weekday rail-passenger traffic in Philadelphia's Center City are taken from Lichstein (2) and from weekly traffic reports of the Port Authority Transit Corporation and Conrail monthly reports to the Southeastern Pennsylvania Transportation Authority. Penn Center traffic represents 87 percent of average weekday traffic, and Market East traffic represents 53 percent.

Beginning in 1958, studies determined that commercial viability east of City Hall (the retail area) depended on better access from the dominant commuter rail system west of City Hall (1, p. 9). The east-side Reading Railway System was using an 85-year-old elevated structure to reach an equally old terminal. The two problems of access and an inadequate terminal could be solved by extending the underground Philadelphia Division (Pennsylvania Railroad) from west to east and continuing on with through trains, just as the subways operate from one side of the city to the other. City planners and policymakers were quick to adopt this through-route concept, but funding it proved even more difficult than the extensive engineering problems.

The below-grade commuter rail station west of City Hall under Penn Center at 15th and 16th Streets could not connect directly with the elevated structure to the east. A railroad subway was unavoidable, but it would have to cross two other operating subways and pass under the Reading Terminal while that station was still in use. Planners and developers preserved right-of-way wherever possible. Filbert and Darien Streets were selected for the route. Because a four-track structure was necessary, additional property had to be acquired, often

Figure 2. Thirty-year trend of urban transit travel by submode.

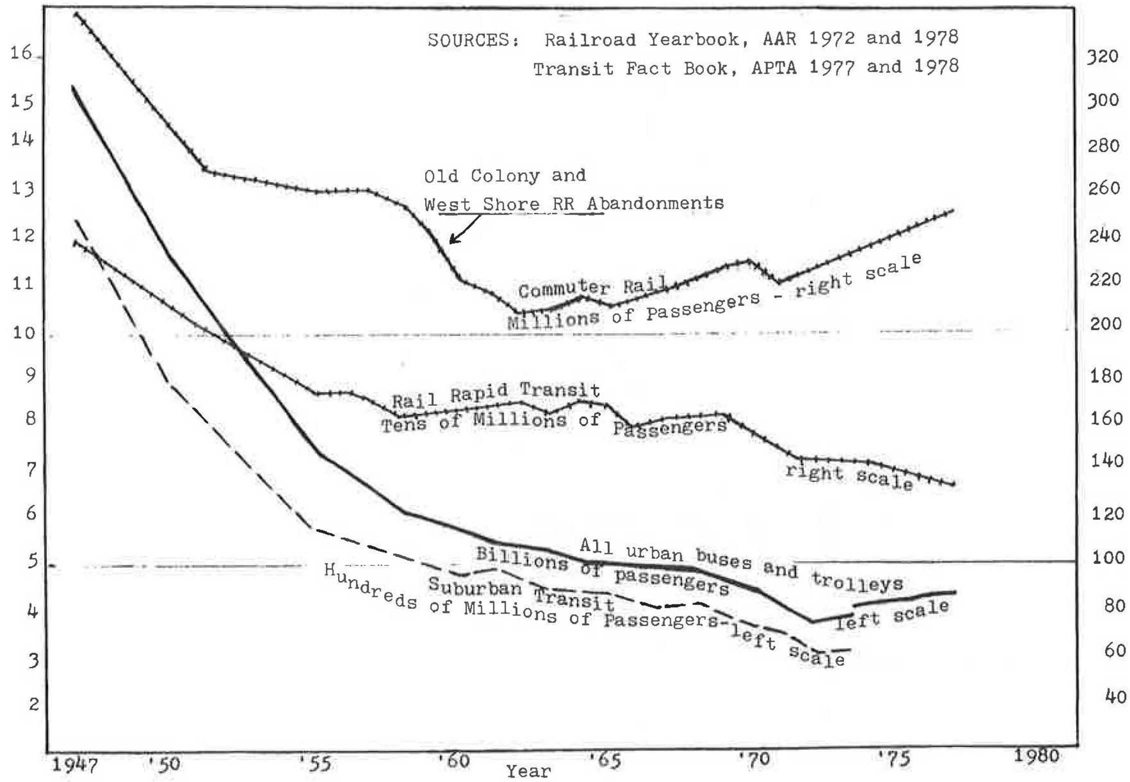
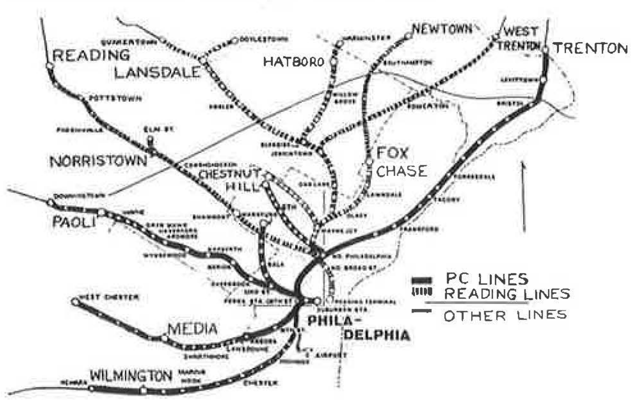


Figure 3. Philadelphia commuter rail system: 1979.



through the redevelopment process.

It was a great challenge, but it developed equally great support from policymakers. It also generated intense opposition from neighborhood groups who were not interested in arguments about improving the city's tax base and did not seem to understand the difference between federal capital grants and discretionary Section 5 formula grants. These people envisioned a diversion of capital funds to cover the growing operating losses of the bus system. Public debate did not help. The difficulty stemmed from a perception of poor bus service brought on by mechanical failures in new buses and by serious service irregularities caused by traffic conditions on Philadelphia's narrow streets (e.g., both legal and illegal parking at the curb).

The proposed downtown four-track subway with dual center-island platforms, plus the access ramp to the Ninth Street elevated structure, was finally estimated to cost $307 000 000. This is a huge sum for a 2.7-km (1.7-mile) route, but in view of complications with a number of downtown underground utilities and other subways, electric railroad clearances, and the fact that the new subway is four tracks in width, the cost is reasonable. It is equivalent to $56 million/double track-km ($90 million/mile), which is not out of line with other subway work in 1979.

PROJECT JUSTIFICATION

It is felt that the Center City Commuter Railroad Connection will provide efficient mobility for people and also sustain and improve the economy of the area served by achieving the following results:

1. Less costly commuter train operation,
2. Increased train patronage and revenue,
3. Reduced highway travel in congested areas,
4. Reduced automobile parking space and cost,
5. Wider access to more of the CBD,
6. Easier and more convenient crosstown travel,
7. Increased property values and tax yields,
8. Greater travel safety,
9. Reduced energy consumption, and
10. Greater mobility for the transportation disadvantaged.

Less Costly Commuter Train Operation

Annual commuter rail operating costs, as contracted with Conrail, approximate $80 million for 685 million passenger-km (425 million passenger miles). [In comparison, the Philadelphia rapid transit system serves roughly 806 million annual passenger-km (500 million passenger miles) at a cost of $40 million.] However, the cost of extending subway-elevated service of lesser quality (more standees)

Figure 4. Increase in share of urban transit work load carried by rail rapid transit and commuter rail.

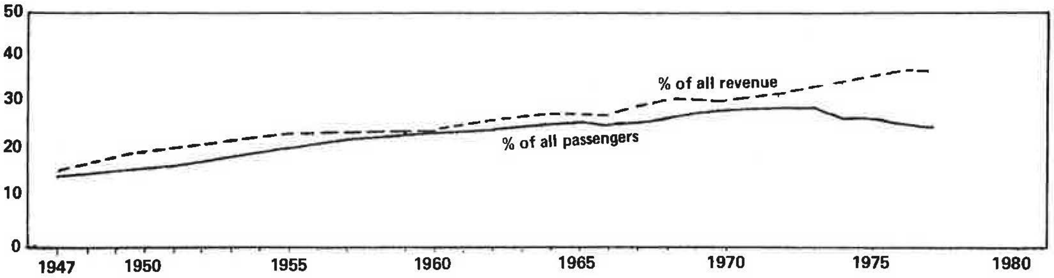


Figure 5. Center City Commuter Railroad Connection: Philadelphia CBD.

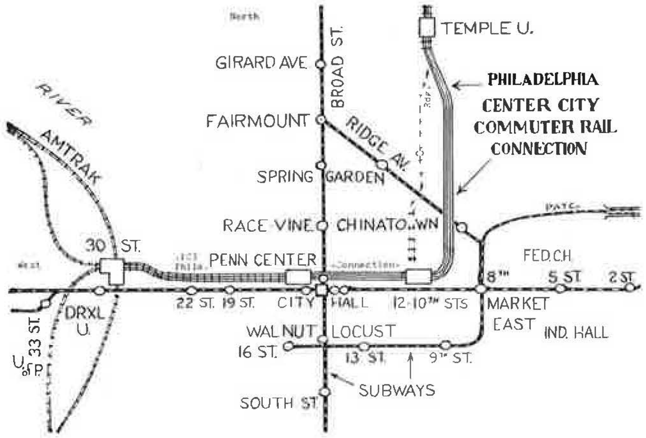


Table 1. Center City average weekday rail-passenger traffic.

Rail Line	Weekday Passengers: Penn Center	Weekday Passengers: Market East	Weekday Passengers: Total
Market-Frankford subway el	200 000	200 000	200 000
Broad Street subway trunk	125 000	0	125 000
Ridge Avenue subway (Broad Street)	0	8 000	8 000
Woodland Avenue subway	60 000	0	60 000
South Jersey Rapid Transit	21 000[a]	42 000	42 000
Conrail			
Philadelphia Division	71 000	0	71 000
Reading District	0[b]	42 000	42 000
Total	477 000	292 000	548 000

[a] Direct South Jersey service west of Broad Street is a 6-min brisk walk from Penn Center. To reflect this longer walking distance, or the alternate cost of an extra fare transfer, the count for Penn Center has arbitrarily been given only half weight.
[b] Part of Penn Center is within walking distance of the Reading Terminal, but any weight given to this fact would merely add to the disparity between Penn Center and Market East.

to another 356 km (220 miles) of right-of-way would be prohibitive by any measure, certainly in excess of $10 billion. Transit bus service in Philadelphia costs approximately 13¢/passenger-km (21¢/passenger mile) for a slower service with more standees (5, Table 15, p. 25). The present commuter rail service is the lowest-cost alternative when one considers both capital and operating costs and the quality of the service rendered. In essence, it is the only practical alternative. The highway system could not absorb the additional 25 000 peak-hour riders into and out of the CBD, nor could parking facilities accommodate them (1, p. 45).

Since rail commuters are being moved at 12¢/passenger-km (19.5¢/passenger mile) and the alternatives to such service mean higher costs and less quality, it becomes urgent to find methods of reducing rail costs without cutting rail service. Subsidies are limited. The present arrangement of two independent and separated rail commuter operations involves the operation of 700 trains/weekday. A connected and integrated operation, such as the one that will result from the commuter rail connection, will reduce the number of trains by half but double the length of their runs.

One result of this is that turnaround time will be cut in half. In major terminals, this averages 15 min/round trip and includes mandatory car inspection, crew changes, adjustment of train size, and recovery time. Straight-through operation will require only 3 or 4 min for the added distance between the two present terminals, which includes loading time.

The net saving of 12 min on a 2.5-min peak headway will approximate five train sets with five train crews. One six-car train represents a new investment of nearly $6 million and annual operating costs of $900 000 ($150 000/car). Saving five of these six-car trains should save $30 million in capital and $4.8 million in annual operating expenses, worth $54 million capitalized at normal government bond interest rates (6, p. 382). In other terms, a reduction of 5.5 percent in total system operating expenses can be anticipated.

A more precise estimate can be formulated by assigning cars and crews to the new service schedules. This has been done but, because of continuing schedule adjustments, it must be updated. An example for one pair of lines is given in Table 2. In that case, one of the West Trenton crews would be shifted to Newton when that line is electrified, reducing the Manayunk-West Trenton crews by one but retaining all 38 trains and the crew saving of three. Train kilometers for the shifted crew are not given in the table, nor are the Newtown trains counted. (The Newtown trains would serve a portion of the West Trenton line, which would account for the difference between the 45 trains currently used and the 38 proposed.)

Increased Train Patronage and Revenue

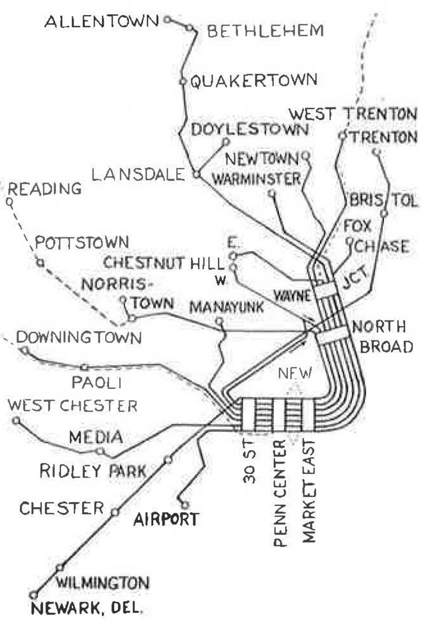
The second economic gain that will result from an integrated commuter rail operation will be revenue increases generated by through-routed-trip time savings and more direct delivery to additional CBD destinations. Modal-split analyses have determined that from 13 000 to 18 000 additional rail trips/weekday will be made to and from CBD origins and destinations by people who cannot, or will not, walk from their closest present station to their activity center and who are unwilling to use slow surface transportation or pay the 50¢ added subway fare. Time and convenience, however, are more important than fare. The 3- or 4-min extended run of the trains to the other side of downtown will replace a 7-min inbound subway link that costs 50¢ and

Table 2. Current and proposed assignment of trains and crews: West Trenton-Manayunk interlocked schedule (Monday-Friday).

Item	Trains	Train Crews	Train Kilometers	Crew Hours
1979-1980 operation				
Philadelphia-Manayunk	36	3	522	26:07
Philadelphia-West Trenton	45	11	2292	88:37
Total	81	14	2814	114:44
Proposed for commuter rail connection				
Manayunk-West Trenton	38	11	2658	89:27
Saving				
Amount	43	3	156	25:17
Percent	53	21	5.5	22

Note: 1 km = 0.62 mile.

Figure 6. Center City Commuter Railroad Connection: optimum interlock of cross-routed lines.



a 12-min outbound run where more time must be allowed to ensure making less frequent train connections. Approximately 2500 person-h/day will be saved.

To avoid perceived travel nuisances, the 13 000 or more weekday trips mentioned above now go to the CBD by automobile (88 percent) or do not go at all (12 percent). The new rail passengers will generate an additional $13 650/weekday and augment commuter rail revenue by $4 million/year (the average commuter fare has been $1.05). The additional riders will need 21 more peak-hour cars, at a capital cost of $21 million and additional operating costs of $3.2 million/year, which reduces the net revenue gain to $0.8 million/year. The added car requirements can be met out of savings made possible by through routing.

A less significant cost reduction will result from the nearly total elimination of a number of slip switches and other crossover tracks on the elevated approach to the old 13-track Reading Terminal. These are both temperamental and costly to maintain and operate. Savings of $500 000/year are anticipated. Straight-through operations will provide much greater capacity because the 13 old tracks are two-way both in and out, with conflicting crossover movements, but the 4 commuter-connection tracks will normally be unidirectional.

Reduced Highway Travel in Congested Areas and Reduced Automobile Parking Costs

The 13 000 or more added weekday rail trips will result in approximately 10 800 fewer automobile trips. The typical commuter travels in a vehicle with an average load of only 1.2 passengers (7, p. a42). Many Philadelphia streets have a total capacity of only 500 vehicles/h because of their 8-m (26-ft) width and the fact that parking is permitted. All key arteries are at volume-capacity equilibrium or worse at peak hours; Interstate highway travel is in level of service C or D or worse (1, p. 45). Automobile travel speeds should increase when trip makers shift to rail service in large numbers. In simplistic terms, the rail improvement should provide (a) the equivalent of one more expressway lane in areas where such a lane would cost $10 million/km ($16 million/mile) or more and (b) four more lanes of city street, which are unobtainable at any price. At least 8 km (5 miles) of freeway lanes worth $80 million can be credited to the rail project as a meaningful saving. Savings resulting from less congestion on the city streets are not so readily subject to approximation, but central parking demand will be reduced by 5000 spaces at a first cost of $40 million and additional annual operating costs of $3 million/year.

The marginal operating cost of the automobile kilometers traveled will approximate commuter rail fares, but about one-fourth of the less-used automobiles will be retired, and this will save $1.20/trip or $1 million/year.

Wider Access to the CBD

New trips to Center City (not additional trips to the region) will result from improved accessibility. The 70 000-passengers/day Philadelphia Division terminates at 15th Street within reasonable walking access to 12th Street. However, the major department-store cluster is between Eighth and Tenth Streets, the new federal court house and office building is at Seventh Street, Independence Mall is at Sixth Street, and related attractions are east of that. Temple University, which has 31 000 students (2, p. 309), has no acceptably convenient access from the western rail commuter lines but will have such access through the Center City Commuter Railroad Connection. There is a Temple University station on the Reading line.

Conversely, the Reading District lines now terminate at 12th Street in central Philadelphia, which limits walking distance westward to 16th Street. The Penn Center development extends west to 20th Street, and Amtrak and University City (University of Pennsylvania and Drexel University with 40 000 students) are at 30th Street. The through routing of trains will give Reading passengers access to these major attractions.

There will also be expanded reverse commuting opportunities for low-income and minority residents of the inner city. It is estimated that 2500 of these currently use the Reading rail lines to and from employment in the northern suburbs, but they have no such convenient access to employment locations in the western suburbs. In the other direction, low-income areas in west Philadelphia have poor access to trains to northeastern employment and will gain new opportunities with the new commuter rail connection.

It is true that for 50¢, in addition to two rail fares, all of these trips could be made today by using the transit system to connect, but the time cost is even more prohibitive than the cash fare. Suburban employment starts as early as 7:00 or 7:30 a.m. The uncertainty of precise transit connections requires ample margin for transfer, and headways have not reached their best by 5:30 a.m. Many of the disadvantaged seek to drive, or do not go at all, rather than get up at 4:45 a.m. each day.

Easier Crosstown Travel

Everyone now realizes that most regional trips are unrelated to the CBD. To accommodate this reality, public transportation must offer more than CBD service. Unfortunately, only the CBD has sufficient demand to support rail, or any, service. The Center City Commuter Railroad Connection will connect one set of 100 outlying rail stations with another set of more than 100 stations. The expansion of travel opportunity is enormous, but the demand is not. Even so, if a 2.5 percent gain in patronage were to result from this additional accessibility, it would add 3000 person trips/weekday.

The Philadelphia International Airport is an exception to this low demand. At this major airport, the commuter connection will offer reasonably direct access across town to the 100 stations that would not otherwise have it. Suburbanites are the most frequent air travelers. The suggested route diagram (see Figure 6) shows the opportunity for direct one-seat airport access with no parking charges and for the easy transfer of all others across the same platform.

Increased Property Values and Tax Yields

It is an axiom that ease of access generates land values by focusing activity. The promise of commuter rail access for the western suburbs to Market Street east of City Hall has already begun to stimulate the redevelopment and revitalization process. The only totally new, large, downtown department-store building in the nation in many years has recently been opened just east of the Market East commuter rail station now under construction. The store is on aerial rights over the tunnel. Developers are now negotiating for new office buildings and shopping malls closer to the station (8). Still others are expected to follow.

These activities employ people and pay taxes. The employees generate other activity, which also pays taxes. The city thus regains vitality. For each $100 million of new investment generated, real estate taxes yield another $25 million/year. Local income taxes increase by a similar amount. The city confidently anticipates almost $20 million/year in additional income to result from the commuter rail project (1, Table E324, p. 107).

Greater Travel Safety

Commuter rail is one of the safest travel modes: It has a long-term record of 0.37¢/passenger-km (0.6¢/passenger mile) in liability costs and a fatality rate of only 0.6/billion passenger-km (0.9/billion passenger mile). Automobile travel exhibits a liability cost in cities that is four times as great: approximately 1.55¢/billion passenger-km (2.5¢/passenger mile). The urban-area fatality rate for automobiles is unacceptably high: almost 15.5 fatalities/billion passenger-km (25 fatalities/billion passenger miles). The savings on incremental increases in commuter-train use generated by the commuter connection will approximate $1.5 million/year and three lives every two years.

Reduced Energy Consumption

Commuter rail service with frequent stops consumes 24 MJ/car-km (11 kW•h/car mile). With an actual 36 passenger-km/car-km, commuter rail consumes 0.67 MJ/passenger-km (0.3 kW•h/passenger mile) in congested areas (3, Table 7, p. 11). The automobile alternative at commuter occupancy rates is about 10 passenger-km/L (24 passenger miles/gal). This is 1.2 MJ/passenger-km (0.56 kW•h/passenger mile)--84 percent more than for commuter rail. If stop-and-go driving were singled out, automobile energy consumption would be even higher. If the energy source is considered, the incremental automobile kilometer is on foreign oil whereas the train kilometer is on a mixture of domestic hydro, coal, nuclear, and oil, the oil portion of which can be minimized or eliminated.

Since 88.5 million additional passenger-km (55 million passenger miles) is estimated to result from improved service annually, the energy consumption will be equivalent to 4.8 million L (1.2 million gal) of oil, but the same trips now going by automobile are consuming 8.7 million L (2.3 million gal). The saving of almost 4 million L/year (1 million gal/year) is worth $750 000 directly and will save $1.2 million at the federal level as a result of the reduced balance-of-payments deficit abroad. It will divert energy supply from foreign oil to domestic alternatives, some of which are renewable (such as water power).

The energy problem was not a specific planning factor in priority-ranking this project, but the energy problem may result in still further demand for rail service.

Greater Mobility for the Transportation Disadvantaged

With 200 commuter rail stations in southeastern Pennsylvania, the rail system offers geographic coverage that is not feasible by other modes because of the extended distances and low densities in the suburbs. The new Market East station is being constructed with full accessibility for the handicapped. Half fares are offered to the elderly and the handicapped. Other reconstructed suburban stations will also offer access for the handicapped. The Penn Center station (16th Street) already has elevators at trainside. At most stations, the conductor can be assisted by other trainmen in helping many of the handicapped on and off. Benefits for the economically disadvantaged have already been described.

OTHER PROBLEMS

The operation of underground passenger trains presents serious problems where stations would be served by diesel-powered units. In the Philadelphia area, all Philadelphia Division trains are electric, but 18 rail diesel cars and two locomotives are required on the Reading District line to reach Bethlehem, Quakertown, Newtown, Pottstown, Reading, and Pottsville, which have a combined city population of 350 000. The urbanized area that includes these stations has nearly twice that population, and travel is increasing.

The Pennsylvania General Assembly has enacted legislation to fund its share of the cost of electrifying the Newtown branch. Some diesel trains will have to transfer passengers to electric trains at outlying stations. Higher-volume diesel trains may have to be towed through the tunnel by electric locomotives.

Table 3. Current weekday operations of Philadelphia Division (west) and Reading District (east) lines.

Line	Trunk Route	Length (km)	Avg Daily Traffic (000s)	Base Headway (min)
Philadelphia Division	Paoli	32	26.0	30
	West Chester	45	12.5	30
	Chestnut Hill West	19	10.0	30
	Wilmington	43	8.5	60
	Trenton	54	7.5	60
	Airport (new)	14	4.0	30
	Manayunk	14	2.0	90
	Total		70.5	
Reading District	North Penn	56	15.0	30
	Chestnut Hill East	18	8.0	30
	Fox Chase	18	6.0	60
	Warminster	32	5.5	60
	West Trenton	53	4.5	60
	Norristown	30	3.0	60
	Total		42.0	

Note: 1 km = 0.62 mile.

Table 4. Statistical realignment of west and east commuter rail lines.

Trunk Route	Length (km)	Avg Daily Traffic (000s)	Base Headway (min)
Paoli-North Penn	89	46 000	30
West Chester-Chestnut Hill East	63	23 000	30
Chestnut Hill West-Fox Chase	37	18 500	45
Wilmington-Warminster	76	16 000	60
Trenton-West Trenton	108	13 500	60
Airport-Norristown	45	8 000	45
Manayunk-Newton (el)	57	3 000	90
Total		128 000	

Note: 1 km = 0.62 mile.

Table 5. Optimal cross-routing of west and east commuter rail lines.

Trunk Route	Length (km)	Avg Daily Traffic (000s)	Base Headway (min)
Paoli-Chestnut Hill East	50	38 000	30
West Chester-North Penn	102	31 000	30
Wilmington-Norristown	74	13 000	60
Chestnut Hill West loop	19	12 000	30
Trenton-Newtown	97	10 000	60
Airport-Fox Chase	32	9 000	60
Airport-Warminster	47	8 500	60
West Trenton-Manayunk	68	7 500	60
Total		129 000	

Note: 1 km = 0.62 mile.

OPERATIONAL CONSIDERATIONS

Since individual stub-end lines vary in length from 14 to 56 km (9-35 miles) in territory where operation is electrified, it is no simple matter to pair off and interline the 13 present lines into 6 or 7 longer lines that vary in length from 32 to 109 km (20-68 miles). The cars and crews must expend the resources to cover these distances. The lines vary in patronage from <10 to >80 passengers/peak min one way. A delicate balance must be struck between kilometers and volume as well as service facilities and crew "turf". Car and crew movements must be balanced to restore all resources to the beginning point for the next day's operation, within the hours of service law and with a minimum of the wasted effort known as deadheading.

Table 6. Benefits and costs of Center City Commuter Railroad Connection.

Item	Millions of Dollars: Annualized	Capitalized
Benefits		
Need for fewer rail cars	2.5	30.0
Reduced operating cost of fewer cars	4.5	54.0
Revenue from additional riders	4.0	48.0
Elimination of Ridge Avenue slip switches	0.5	6.0
Avoidance of added freeway capacity	6.67	80.0
Avoidance of added CBD parking construction	3.33	40.0
Reduced cost of parking operations	3.0	36.0
Nonreplacement of automobiles	1.0	12.0
Reduced cost of accident liability	1.5	18.0
Reduced consumption of foreign oil	1.2	14.4
City gains on tax yields	20.0	240.0
Total	48.2	578.4
Costs		
Cars to carry additional riders	1.75	21.0
Operating cost of added cars	3.2	38.4
Total	4.95	59.4
Project cost	25.57	307.0

Current weekday activity for each of the two districts is given in Table 3. Pairing or cross-routing of these lines to use the commuter connection presents difficulties because there are seven routes on the west, with 70 000 passengers, and only six routes on the east, with 42 000 passengers. The west has, or will have, four 30-min-headway routes, but there are only two such on the east. There are only three 60-min-headway routes on the west, but there are four on the east.

The purely statistical cross-routing or interlocking of lines in order of volume would establish the pattern given in Table 4.

There are many practical limitations to this purely statistical realignment. Yard facilities and a day's work do not balance out. An airport-Norristown linkup would have very poor service facilities--an unjustified headway to Norristown and an inadequate frequency to effectively serve the airport. A Trenton-West Trenton through route would have more than its share of yard facilities on too long a line. A single round trip would be far short of a day's pay (which is guaranteed), but two round trips would involve 76 percent excess kilometers. As with the airport-Norristown linkup, the U-shaped route configuration would generate little crosstown riding potential. Similar problems result on other lines.

Obviously, what is essential is a more sophisticated through-routing pattern that offers a good balance of matching headways, yard facilities, optimal crew mileage, and crosstown riding potential. Such an optimal arrangement is shown in Figure 6 and given in Table 5. This cross-routing pattern provides a far superior service pattern and operating arrangement. The airport gets not only the necessary 30-min headway but also direct one-seat service for almost four times as many riders and economical headways at the other ends of the line. The Chestnut Hill West line has been made into a loop to balance the lines on each end of the tunnel (Figure 6).

The West Chester-North Penn interlock would appear to be too long for two round trips within the basic service day, but, in contrast to the Trenton-West Trenton problem in Table 4, this link has frequently used short turn-back points at Media and Lansdale, which cuts the one-way trip for most crews to 65 km (40 miles). Two round trips would be only 7 percent over the basic day. The 1000 additional passengers are attributed to the improved cross-routing with its better potential for crosstown trip making.

BENEFIT/COST RATIOS

Table 6 outlines the 1.7 benefit/cost (B/C) ratio estimated for the Philadelphia project. The relationship between annualized and capital costs is based on the capital recovery factor of 8.33 percent, which is equivalent to 6 percent interest on a 22-year amortization or 7 percent on a 27-year period. The B/C ratio would increase to 1.9 if a 35-year project life were assumed at 6.5 percent interest. Subways have a much longer life than this. Commuter rail cars usually operate effectively for 35 years before replacement. The value of time saved has not been taken as a cash saving.

Thorough independent analyses by the Transportation Systems Center of the U.S. Department of Transportation and by the Delaware Valley Regional Planning Commission technical staff have also determined B/C ratios of 1.7 or better.

SUMMARY

With costs and highway congestion inexorably increasing, and with both cities and the energy supply declining, major projects that will reduce the cost of travel while improving mobility are becoming essential to maintain convenient access and travel efficiency in metropolitan areas. Construction alone may not provide the solution. Care in design and skill in implementation will be required to achieve the projected results.

The Center City Commuter Railroad Connection may not equal the impact of the Hudson River tunnels of 1910, but it will certainly tend in that direction. The favorable impact is already apparent in Philadelphia's Center City.

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Abridgment

Rapid Transit Time and Energy Requirements

W.H.T. HOLDEN

The results of an analysis to compare the trade-off between time and energy in the propulsion of a rapid transit train are discussed. Faster schedules consume more energy but reduce other operating costs and are an asset in attracting riders. Methods of reducing energy consumption, mainly by recovery of all or part of the kinetic energy used, are also described.

In planning and operating a rapid transit system today, the energy required for operation is a major consideration because of the rapid increase in energy costs. Faster schedule speeds are desirable because they increase patronage and reduce operating costs for train attendants and the quantity of equipment required. It is the purpose of this paper to determine the energy increase attributable to higher speed and the corresponding reduction in time to operate a train for a number of interstation distances.

RAPID TRANSIT TRAIN

For this analysis, a theoretical train has been assumed, the properties of which are based on those of the New York R-46 rapid transit car. The quantities that are significant for this purpose are (a) car dimensions (length of 23 m and area of cross section of 10 m^2), (b) weight with one-half maximum load (60 000 kg), (c) train consist (8 cars), and (d) rotational inertia, which is taken as 10 percent of empty car weight, so that inertial mass for the train is 525 600 kg.

The following ranges of speeds and accelerations are considered: maximum speeds of 20, 25, 30, and 35 m/s and initial accelerations of 0.5, 1.0, and 1.5 m/s^2.

SPEED-TIME AND DISTANCE-TIME RELATIONS

It is necessary to express speed-time and distance-time relations in terms of a mathematical formula to permit the necessary integrations for energy determination during acceleration. The following exponential approximation has been adopted for this purpose:

$$V_t = V_o[1 - \exp(-t/T_o)] \quad (1)$$

where

V_t = speed t seconds after a start at t = 0,
V_o = maximum speed, and
T_o = maximum speed divided by initial acceleration, or V_o/A_o.

By integrating Equation 1 from t = 0 to t = t, it is found that

$$D_t = V_o t - V_t T_o \quad (2)$$

where D_t is speed at time t starting at t = 0.

When $t = 3T_o$, Equation 1 indicates that $V_t = 0.9502V_o$. The 5 percent difference from $V_t = V_o$ for this value of t is neglected and, for $t = 3T_o$ or greater, it is assumed that $V_t = V_o$. This leads to $D_t = 2V_oT_o$ when $t = 3T_o$.

Braking is assumed to be at the same rate as initial acceleration. Then the braking distance (D_b) is $(1/2)V_t^2/A_o$; if $V_t = V_o$, this becomes $D_b = (1/2)V_oT_o$. It follows that the minimum length of run, start to stop, in which V_o is attained is $2.5V_oT_o$. Braking time (t_b) is V_t/A_o, and equals T_o if $V_t = V_o$.

Table 1. Dimensionless values for speed-time and distance-time relations.

t/T_o	V_t/V_o	D_t/V_oT_o	D_1/V_oT_o	t_1/T_o
0.1	0.0952	0.0048	0.0053	0.0103
0.2	0.1813	0.0187	0.0351	0.3813
0.3	0.2592	0.0408	0.0858	0.5592
0.4	0.3297	0.0703	0.1247	0.7297
0.5	0.3935	0.1065	0.1345	0.8935
0.6	0.4517	0.1483	0.2264	1.0317
0.7	0.5034	0.1966	0.3233	1.2034
0.8	0.5507	0.2493	0.4009	1.3507
0.9	0.5934	0.3066	0.4827	1.4934
1.0	0.6321	0.3679	0.5677	1.6321
1.1	0.6671	0.4329	0.6554	1.7671
1.2	0.6988	0.5012	0.7454	1.8988
1.3	0.7275	0.5725	0.8371	2.0275
1.4	0.7534	0.6466	0.9304	2.1534
1.5	0.7769	0.7231	1.0249	2.2769
1.6	0.7981	0.8019	1.1166	2.3981
1.7	0.8173	0.8827	1.2167	2.5173
1.8	0.8347	0.9653	1.3137	2.6347
1.9	0.8504	1.0500	1.4116	2.7504
2.0	0.8647	1.1357	1.5091	2.8647
2.1	0.8775	1.2225	1.6075	2.9775
2.2	0.8892	1.3108	1.7061	3.0892
2.3	0.8997	1.4003	1.8050	3.1997
2.4	0.9093	1.4907	1.9041	3.3093
2.5	0.9179	1.5821	2.0034	3.4179
2.6	0.9257	1.6743	2.1028	3.5257
2.7	0.9328	1.7672	2.2637	3.6328
2.8	0.9392	1.8608	2.3018	3.7392
2.9	0.9450	1.9550	2.4015	3.8450
3.0	0.9502[a]	2.0498[b]	2.5012[c]	3.9502[d]

[a]Use 1.0000.
[b]Use 2.00.
[c]Use 2.50.
[d]Use 4.00.

RUN LENGTHS

The run lengths, or interstation intervals, considered here are 800, 1600, and 3200 m. If D_r is run length, then $D_r - 2.5V_oT_o$ must be positive if V_o is attained during the run. The distance ($D_f = D_r - 2.5V_oT_o$) is run in a time D_f/V_o in this case, and drag forces are constant at the V_o value during this time t_f. If $D_r - 2.5V_oT_o$ is negative, then it is necessary to determine V_t and t and also D_b and t_b. This must be done by trial and error, since it is not possible to solve the equations directly for t because it occurs as both an exponential and an algebraic term. Graphical methods may be used.

DIMENSIONLESS FORM OF ABOVE RELATIONS

If we divide Equation 1 by V_o, we have

$$V_t/V_o = 1 - \exp(-t/T_o) \qquad (3)$$

where V_t/V_o has a maximum value of unity and states V_t as a fraction of V_o. Similarly, Equation 2 can be divided by V_oT_o, which results in

$$D_t/V_oT_o = t/T_o - V_t/V_o \qquad (4)$$

In addition, $D_b/V_oT_o = (1/2)(V_t/V_o)^2$ and, if $V_t/V_o = 1$, $D_b/V_oT_o = 1/2$.

A quantity D_1 is used in this determination of energy and time. It is the distance run in attaining maximum speed in a run plus the distance required to brake to a halt from that speed. At $t = 3.0T_o$, $D_1 = 2.500V_oT_o$. There is also a time t_1, which is the time it takes to run the distance D_1. At $t = 3.0T_o$, $t_1 = 4T_o$.

Table 1 gives dimensionless values for these relations, where

Table 2. Time and energy comparisons for various runs and performances.

Acceleration (m/s^2)	Time or Energy	800-m Run				1600-m Run				3200-m Run			
0.5	V_o (m/s)	20	25	30	35	20	25	30	35	20	25	30	35
	T_o(m/s)	40	50	60	70	40	50	60	70	40	50	60	70
	V_oT_o (m/s)	800	1250	1800	2450	800	1250	1800	2450	800	1250	1800	2450
	Max V (m/s)	15.4	16.3	17.2	18.9	18.4	20.7	22.3	23.2	20	25	24.8	29.2
	U_k (MJ)	62.5	70.3	77.6	94.1	88.8	109.8	130.5	141	105	164	190	223
	U_a (MJ)	14.4	43.9	53.3	80.7	43.4	42.7	91	89.2	38	76	140	278
	U_f (MJ)	0	0	0	0	0	0	0	0	28	2	0	0
	U_r (MJ)	76.9	114.2	131	175	132	153	222	230	171	242	330	501
	t_r (s)	90	86	86	92	137	130	126	123	220	203	190	186
1.0	V_o (m/s)	20	25	30	35	20	25	30	35	20	25	30	35
	T_o (m/s)	20	25	30	35	20	25	30	35	20	25	30	35
	V_oT_o (m/s)	400	625	900	1225	400	625	900	1225	400	625	900	1225
	Max V (m/s)	17.3	18.2	21.8	22.6	20	25	26.7	29.2	20	25	30	35
	U_k (MJ)	78.6	113	151	143	105	164	187	223	105	164	237	322
	U_a (MJ)	15.4	16.5	35.7	47.2	19	38	54	60.4	19	38	69	115
	U_f (MJ)	0	0	0	0	1.4	1	0	0	52	49	27	6
	U_r (MJ)	111	129	187	190	125	203	241	287	176	251	333	443
	t_r (s)	57	65	72	62	100	89	95	92	190	166	153	144
1.5	V_o (m/s)	20	25	30	35	20	25	30	35	20	25	30	35
	T_o (m/s)	13.33	16.67	20	23.33	13.33	16.67	20	23.33	13.33	16.67	20	23.33
	V_oT_o (m/s)	267	414	600	817	267	414	600	817	267	414	600	817
	Max V (m/s)	20	22.8	25.1	26.8	20	25	30	32	20	25	30	35
	U_k (MJ)	105	136	166	188	105	164	237	269	105	164	237	322
	U_a (MJ)	32	24	11	42	13	16	45	63	13	16	45	77
	U_f (MJ)	3	0	0	0	22	17	4	0	56	65	65	55
	U_r (MJ)	140	160	177	230	140	197	286	332	174	245	347	454
	t_r (s)	60	56	53	52	100	89	83	86	180	153	137	127

Table 3. Input energy per unit energies and schedule speeds.

Run Length (m)	Initial Acceleration (m/s^2)	Balancing Speed (m/s)	Input Energy (MJ)	Energy per Kilometer (MJ)	Energy per Car Kilometer (MJ)	Power per Car Kilometer (MJ)	Schedule Speed (m/s)
800	0.5	20	96	120	15	6.8	7.3
		25	143	179	22	9.9	7.6
		30	164	205	26	11.7	7.6
		35	219	274	34	15.3	7.14
	1.0	20	139	173	20.6	20.6	13
		25	108	136	17	17	11.8
		30	108	136	17	17	10.9
		35	115	144	18	18	12.2
	1.5	20	175	219	27.4	27.4	10
		25	200	250	31.3	31.4	10.5
		30	221	276	34.5	34.6	11
		35	288	360	45	45	11.1
1600	0.5	20	165	103	13	5.9	10.2
		25	191	119	15	6.8	10.7
		30	278	174	22	9.9	11.0
		35	288	180	23	10.4	11.2
	1.0	20	156	98	12	12	13.3
		25	254	159	20	9	14.7
		30	301	188	24	24	13.9
		35	359	224	28	13.7	13.9
	1.5	20	175	109	13.6	13.7	13
		25	246	154	19.3	19.5	14.7
		30	358	224	28	28	15.5
		35	336	210	26.3	26.3	15.1
3200	0.5	20	214	67	8	3.6	13.3
		25	254	79	10	4.5	14.4
		30	413	129	16	16	14.4
		35	626	195	29.5	24.5	15.5
	1.0	20	220	69	9	9	15.2
		25	314	99	12	12.6	17.2
		30	416	130	16	16	18.5
		35	554	173	21	20.6	19.5
	1.5	20	218	68	8.5	8.6	18
		25	306	96	12	12	18.5
		30	434	136	17	17	20.4
		35	403	126	16	16	21.8

Note: Input energy at 80 percent efficiency conversion and distribution, based on 20-s station delay or dwell time.

$V_tV_o = 1 - \exp(-t/T_o)$,
$D_t = t/T_o - V_t/V_o$,
$D_1 = D_t + (1/2)(V_t/V_o)^2$, and
$t_1/T_o = t/T_o + V_t/V_o$.

DRAG FORCES OR TRAIN RESISTANCE

Any moving vehicle encounters frictional forces that oppose motion. These are not readily determined analytically, and empirical formulas derived from tests are used to determine these forces. Davis and Dover have derived such relations. The Dover formula for drag force attributable to train resistance (F_d, in newtons) is

$$F_d = mg(0.001\,832 + 0.000\,054\,8V) + AV^2(0.6702 + 0.0095nL) \quad (5)$$

where

m = mass of train (kg),
g = acceleration of gravity (9.81 m/s^2),
V = speed (m/s),
A = area of cross section (m^2), and
n = number of cars L meters in length in the train.

When one introduces the numbers from the train data cited earlier, this becomes

$$F_d = 8627 + 258V + 24.18V^2 \quad (6)$$

KINETIC ENERGY

The kinetic energy in a mass m in motion at a speed V is $(1/2)mV^2 = U_k$, where U_k is kinetic energy (J), m is inertial mass (kg), and V is speed (m/s). For the train here considered, the inertial mass weight is 65 700 kg. This is the largest component of the energy to propel and accelerate. Part of it is recoverable by regenerative braking systems.

ENERGY TO OVERCOME DRAG FORCES DURING "POWER-ON" PERIOD

The product F_dV is the power required to overcome drag forces at speed V. Integrating the expression for this, which can be derived from Equation 6, results in

$$U_a = 8627\int_0^t V_t\,dt + 258\int_0^t V_t^2\,dt + 24.18\int_0^t V_t^3\,dt \quad (7)$$

where U_a is the energy expended in acceleration to overcome train resistance (MJ). The expression for V_t is that of Equation 1, and thus

$$U_a = 8627V_o\int_0^t [1 - \exp(-t/T_o)]\,dt + 258V_o^2\int_0^t [1 - 2\exp(-t/T_o) + \exp(-2t/T_o)]\,dt + 24.18V_o^3\int_0^t [1 - 3\exp(-t/T_o) + 3\exp(-2t/T_o) - \exp(-3t/T_o)]\,dt \quad (8)$$

The first term above is $8672(V_ot - V_tT_o)$ or

$8672D_t$, where D_t is distance at t = t. The second term results in

$$258V_o[D_t + (1/2)V_{2t}T_o] \quad (9)$$

and the third becomes

$$24.18V_o^2[V_ot - 3V_tT_o + (3/2)V_{2t}T_o + (1/3)V_{3t}T_o] \quad (10)$$

Thus, for times at which full speed is not attained, we have

$$U_a = 8672D_t + 258V_o[D_t + (1/2)V_{2t}T_o] + 24.18V_o^2[V_ot - 3V_tT_o + (3/2)V_{2t}T_o + (1/3)V_{3t}T_o] \quad (11)$$

Note that V_{2t} is speed attained in a time 2t and V_{3t} is that attained in a time 3t.

If t = $3T_o$, it is assumed that V_t approaches V_o, and then Equation 11 becomes

$$U_a = 17\,344V_oT_o + 258V_o(2.5V_oT_o) + 24.18V_o^2[3V_oT_o - 3V_oT_o + (11/6)V_oT_o] \quad (12)$$

or

$$U_a = V_oT_o(17\,344 + 645V_o + 44.33V_o^2) \quad (13)$$

RESULTS IN SPECIFIC CASES

Equations 11 and 13 have been applied to specific cases of four balancing speeds, three acceleration speeds, and three run lengths. The results of these calculations are given in Table 2, where

U_a = energy expended in acceleration to overcome train resistance (MJ),
U_f = energy in full-speed portion of run where speed is constant (MJ),
U_r = total energy for the run (MJ), and
t_r = time required for the run.

Table 3 gives the results in a different form that is more convenient for evaluating the time-energy trade-offs under consideration.

ENERGY CONSERVATION

In view of the current need to conserve energy, it will be of interest to review the data presented here to determine what methods of conservation may be of value. As the energy required for propulsion is directly proportional to car weight, it is obvious that a reduction in weight per unit of capacity is desirable. There is another trade-off here, since weight reduction may involve excessive costs or reduced life of equipment. In addition, since it is essential that buffing strength be adequate to prevent danger in collisions or car damage in coupling, there is also a safety factor.

But, since the largest term in the energy account is kinetic energy (U_k), it will be seen that recovery of some fraction of this term by regenerative braking is an effective method of energy conservation. The problem is then what to do with this energy. With direct-current power distribution, the power supply network may be unable to accept such reverse energy flow because of a lack of load from other trains in the power-on condition or excessive increase in line voltage at the regenerating train. This energy can be stored by diverting it into some type of energy-storage device. Two proven storage devices are available: the storage battery and the flywheel. There is also the question of whether these devices should be on board or on the wayside. The flywheel appears to have economic advantages over the battery, and can be on board or on the wayside. The development of this device to a state that permits wide commercial use should be expedited.

It can also be seen from the data in Tables 2 and 3 that the equipment used should be adapted to the station intervals. High-speed cars with short station spacings appear to waste energy. Long station intervals conserve energy, and it may be possible to adopt skip-stop operation where denser areas necessitate short intervals.

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Rationale for Selection of Light Rail Transit for Pittsburgh's South Hills

E.L. TENNYSON

A project to update the 70-year-old South Hills electric railway system in Allegheny County, Pennsylvania, was among the first such projects to be subjected to intense scrutiny as part of a federally mandated alternatives analysis. The rationale of the accepted solution is examined, and the technical process by which consensus was achieved is described. The data used derive from the alternatives-analysis work of the consultants, from regional planning projections, and from the author's observations and experience in the area. The alternatives analysis did not include a final solution for the downtown Pittsburgh traffic problem, but the subsequent review process, based on good data, led to the conception and acceptance of the Sixth Avenue subway.

For more than 70 years, street railway service has been provided to the southern portion of Allegheny County, Pennsylvania, an area known as the South Hills. As of 1980, most of this rail operation is on private right-of-way. This may account, in part, for its success and continued existence. However, 100-year-old bridges, 70-year-old way and power facilities, and 35-year-old cars cannot continue on indefinitely. The leaders of Allegheny County (of which Pittsburgh is the county seat) recognized this and made plans years ago for a more contemporary replacement facility.

Allegheny County currently has a population of 1.7 million; 458 000 reside in the city of Pittsburgh and 114 553 in the suburbs served by the street railway system. As the table below indicates, both Pittsburgh and Allegheny County are in a population decline but the areas served by the street railways are in a major growth mode (1):

Location	1970 Population	Decennial Population Change (%)
Rail service area		
Beechview	12 965	-3.1
Dormont	12 856	-1.8
Mount Lebanon	30 596	+12.0
Castle Shannon	11 899	+0.5
Bethel Park	34 791	+47.1
Upper Saint Clair (Drake Road)	15 411	+86.0
Library	4 600	+14.0
Total	132 118	+20.5
Allegheny County	1 600 000	-2.0
Pittsburgh	458 651	-14.0

Projections suggest a 1980 population of 45 000 for Bethel Park and 24 000 for Upper Saint Clair. The other communities are projected to stabilize.

The topography is difficult. Two major rivers (the Allegheny and the Monongahela) converge on two sides of the central business district (CBD) to form the Ohio River and the "Golden Triangle". The Golden Triangle is the euphemism given to the very compact, dense, convenient (for pedestrians), and prosperous center of commercial activity in Pittsburgh. Pittsburgh is one of the nation's prime corporate centers and, according to the 1970 U.S. Census, has the fifth highest transit modal-split share in the nation.

On the south side of the CBD, a sharp escarpment known as Mount Washington blocks movement in that direction. To solve this problem, a double-track street railway tunnel was drilled through the mountain 70 years ago on a 6 percent grade. It has recently been paved for joint use by buses but not carpools. The tunnel is at capacity at peak hours. A 50-year-old highway tunnel is nearby, but it is too congested for efficient bus movement.

Because of the presence of many other hills, valleys, and streams, Pittsburgh and Allegheny County have numerous bridges, several of which have had to be closed because of structural deterioration. Much of the land is too steep to use. The highway "pattern" is patternless because of the topography. There can be no grid system, but most valleys have arterials along their bottoms and many ridges have arteries along their spines. Traffic conditions and air quality both need major improvement, by mutual agreement and federal requirement.

There are two trunk street railway corridors that operate south out of the CBD in the Triangle, across the Monongahela River by way of a 100-year-old historical bridge, and up through the tunnel. One of these two routes spans the next valley and then climbs to serve the ridge-top communities of Beechview, Dormont, and Mount Lebanon. There is a bucolic and rustic single-track extension on private right-of-way to Castle Shannon (a borough) 13 km (8 miles) from the CBD by way of this route (route 42/38).

This Dormont-Mount Lebanon line serves 45 percent of the passengers on the present rail system and 38 percent of the passenger kilometers but constitutes only 36 percent of the route kilometers. In Beechview and Mount Lebanon, the tracks occupy major street centers; otherwise, they are on private right-of-way outside the CBD and are double track except as noted. A 2-min peak and 12-min base headway are operated at the busiest seasons of the year. The 11-km (7-mile) Mount Lebanon run consumes 31-37 min, depending on Triangle traffic conditions. This service operates inbound north on Smithfield Street to Seventh Avenue, then outbound south on Grant Street. Average weekday patronage is about 10 000, or 3 million/year. The fare in 1979 was 50 cents. Weekly, monthly, and annual passes for regular riders are offered. Approximately 33 Presidents' Conference Committee (PCC) railcars are required to meet the peak schedule with shopping margin. Buses also serve parts of the same corridor but are not as convenient for the Beechview and Dormont ridge-top communities.

The other corridor or route, which has two outlying branches, hugs the side of Saw Mill Run Valley on private right-of-way through Overbrook. This route has several major bridges and a 4-km (2.5-mile) stretch of single track where topography did not leave room for two tracks. A conventional railroad block signal system protects all movement on this line. This stretch, with its 2-min headways, may be the busiest 4 km of single track anywhere. Buses serve the valley bottom and the opposite side for the first 6 km (4 miles), beyond which point the rails follow PA-88, a shoulderless, winding, two-lane facility that has less capacity than the present peak rail volume (2200 passengers/h one way). This branch carries 11 000 passengers/day and more than 3 million/year.

At Castle Shannon, 11 km (7 miles) and 27 min from the Pittsburgh CBD, the tracks connect with the bucolic extremity of route 42/38. Then, 13 km (8 miles) out at Washington Junction, a single-track branch diverts to Drake Road 5 km (3 miles) beyond. This branch is route 36-Drake, which terminates at the most intensively used park-and-ride lot in the entire region (2, p. 35). The double track continues south as route 35-Library for an additional 8 km (5 miles) through the suburban borough of Bethel Park to the county-line community of Library, a mining research center. The 88 Transit (bus) Line also operates express service along this route to points south but does not attract a heavy volume of local riders. Transit fare to Library was 70 cents in 1979. Route 35 requires 18 cars, and 13 more are required for route 36, including spares.

In addition to a free park-and-ride facility at Washington Junction, pay parking is provided in the Castle Shannon vicinity by private entrepreneurs whose facilities accommodate almost half of the entire metropolitan area's park-and-ride activity (2, Table 7, p. 42). To augment service to these lots, peak-hour short-turn service is operated as far as Castle Shannon as route 37, which requires six cars, including spares.

There is also a route 49 that provides a tunnel bypass and an exceptional view of the city for tourists as it climbs over Mount Washington on a single track up New Arlington Avenue on age-old cobblestones. Except when the tunnel is closed for repairs and route 49 becomes strategic, this route provides only minimal service for minimal demand.

The areas served by routes 35 and 36 have changed from isolated old mining communities to extensive new suburban developments inhabited by two-car, upper-middle-income families. Contrary to generalized regression analyses, the higher incomes and higher automobile ownership create higher levels of transit use in that the park-and-ride mode is used to escape traffic congestion. Transit service on these routes in 1979 was more frequent and more heavily patronized than it was in 1946, when Pittsburgh transit experienced its peak year after four years of gasoline rationing. This growth has increased service frequency to the point of serious and frustrating congestion on the single track. The paradox is evident: Good service has attracted more patronage than it can properly handle without upgrading. Two-way operation on single track requires precise scheduling and tight discipline but, when automobile congestion in the CBD is delaying service, on-time operation becomes impossible. A solution to this problem is urgently needed.

PROPOSED SOLUTION

After federal-aid matching funds were made available for urban transit more than a decade ago, community leaders proposed an automated-guideway system to serve the CBD over a little-used railroad line just east of Grant Street, then south through an abandoned railroad tunnel, and over a new viaduct to reach the route 42/38 rail right-of-way alignment in Beechview, then on over that right-of-way to Dormont, Mount Lebanon, Castle Shannon, almost to Drake Road, near which point it would divert to serve the South Hills Village Regional Shopping Center. This 17-km (10.5-mile) route would have required removal of at-grade street railway facilities, thus aborting operation of routes 42/38 and 36. The future of route 35 was also threatened, since the plans suggested shuttle feeder service rather than the existing direct service. Objections were raised against these impacts, against proposed automated features, and against the cost of the project, but the basic problem was the attempt to replace 35 km (22 miles) of street railway with only 17 km of automated guideway (see Figure 1).

As civic debate continued, the Urban Mass Transportation Administration (UMTA) was developing its alternatives-analysis requirements. It was finally determined that the problem should be subjected to a formal, professional alternatives analysis by experienced engineers and economists. A supervisory task force was created that consisted of city, county, state, and Port Authority Transit representatives. Continuing surveillance was provided by the League of Women Voters. The task force maintained liaison with the principals and the consultants. I was a member of the technical committee of the task force.

Federal funding for 80 percent of the cost was approved on condition that an exclusive-busway alternative be included. Other alternatives were the original Transit Expressway Revenue Line, light rail (a major upgrading of the present system), and rail rapid transit. The do-nothing or null alternative was not realistic because of the problems of deteriorating highways, bridges, and rail transit lines. Peak-hour movement could not continue if nothing were done.

ALTERNATIVES ANALYSIS

The objective of the alternatives analysis was to reduce or eliminate the delays experienced by the present transit system, thus speeding movement and reducing cost, or at least reducing operating cost. All alternatives were designed to meet the speed and capacity requirements of the corridors served in order to provide meaningful comparisons. For the busway, this meant that grade-separated downtown terminal access was needed to avoid serious delay and to provide necessary capacity. Even now, the streets of Pittsburgh's Golden Triangle are often saturated (1, p. III-48).

Exclusive Busway

In addition to a downtown bus terminal with future capacity for 14 000 peak-hour passengers, an adequate crossing of the Monongahela River was necessary. For economic reasons, and to avoid the acquisition of right-of-way, the ridge-top busway was truncated at the Dormont-Mount Lebanon boundary, with mixed traffic operation south of that point. The existing busway in the Saw Mill Run Valley corridor would have been extended through Bethel Park over the present route 35 rail right-of-way. This would have required total abandonment of rail service during construction.

This alternative involved the least capital cost and fewer transfers for passengers, but these advantages were more than offset by higher operating costs, poor CBD distribution, and long headways on the outer ends of the lines as they branched out beyond the busway. Because of capacity and exhaust problems, underground bus stations were not feasible. Since tunnel capacity was not adequate for year-2000 volumes, it would be necessary to reactivate the old abandoned Wabash railroad tunnel sometime before the year 1990, which would require costly approach structures. No effective service could be provided for the area during the construction period, since rail service would have to be removed to facilitate construction and parallel highways are already beyond capacity limits.

Even though use of articulated superbuses was assumed on those routes able to accept them, the labor cost of this alternative was prohibitive. The South Hills have a 20 percent peak-hour one-way ratio to all-day, two-way travel. Some bus drivers could only serve a maximum of 100 passengers/day with 12-m (40-ft) buses. A larger-capacity, or automated, vehicle was clearly required to cope efficiently with this high-volume, higher-peak-loading, commuter-dominated demand.

The use of imported oil was not seriously considered at the time of the study, but it has since become a factor for consideration.

Transit Expressway Revenue Line

The Transit Expressway Revenue Line, which was the original plan, involved the highest first cost without sufficient operational economy to amortize it at any reasonable interest rate. Not only would guideway heating cause a severe problem of energy cost and waste but also extensive and costly feeder bus service would be necessary. Only 17 km (10.5 miles) of the present 35-km (22-mile) rail system would have been replaced with automated facilities. The wider station spacings caused some complaint in local neighborhoods. Because of these adverse economic and service factors, it was not necessary to resolve any problems with automation like those experienced on other large automated transit projects.

Heavy Rail Rapid Transit

The heavy rail alternative was identical to the automated-guideway Transit Expressway Revenue Line except that full-sized steel-wheeled cars would be used. This would reduce the number of units to be automated and avoid the guideway heating problem associated with rubber tires on structures. This alternative offered the lowest operating costs, in spite of the extensive feeder bus system required, but it required a greater investment than light rail to serve fewer passengers over the same area. Since the Sixth Avenue subway alternative investment was not included in the heavy rail estimate, the comparison with light rail lacks this valuable feature. The absence of close access to major department stores and to Pittsburgh's Gateway Center, as well as the need for so much feeder bus service to serve slightly fewer passengers, caused

Figure 1. Light rail transit plan proposed for Allegheny County.

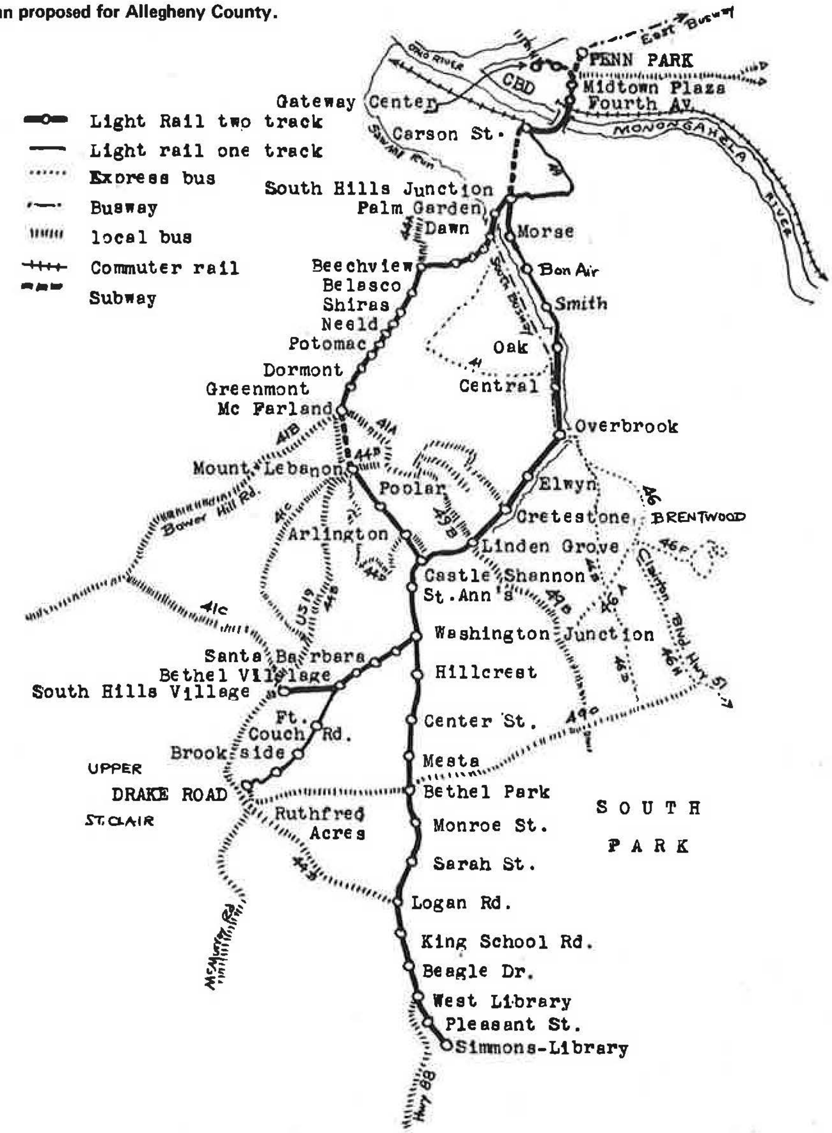
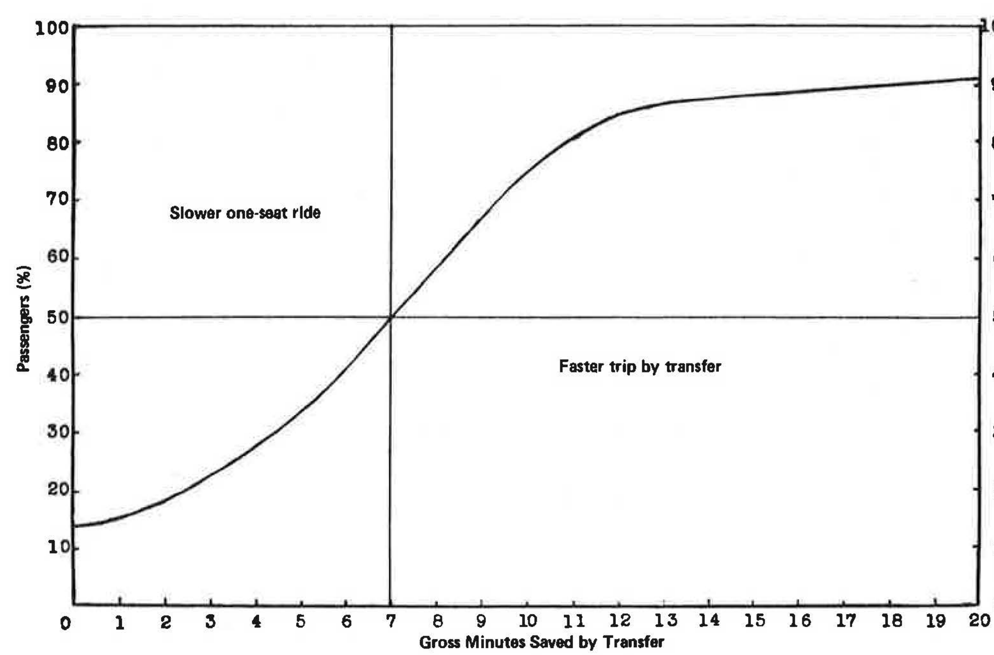


Figure 2. Observed tendency of transit passengers to change vehicles to save time.



the rejection of this alternative, as it had the rejection of the original plan.

Light Rail Transit

Major improvements to the present system proved to be the alternative that would be most cost effective and attract the most riders (1, p. III-44). No present rail riders would be forced to ride feeder buses, although some present bus riders would elect to transfer to rail service to save time. Field studies have determined that passengers will tansfer voluntarily if the time saving is sufficient (see Figure 2). The break-even point (50 percent will and 50 percent will not) occurs at a 7-min gross time saving (about 4 min net).

In addition to upgrading the present system, the new link into South Hills Village Regional Shopping Center would be included. The Port Authority of Allegheny County, which operates the transit system, has already acquired a large adjacent tract for a major shop facility and vehicle storage. Using this area as a base of operations will eliminate nearly an hour of spread time from most operators' penalty time. The location of the present base of operations--at South Hills Junction near the CBD--necessitates an empty outbound move every morning, partly over single track, and a reverse empty move in the evening after passenger movement has been completed.

The Mount Lebanon subway parallel to Washington Road (US-19) was retained in the plan, but a new alignment through Beechview was not. Traffic conditions on US-19 required transit separation, but Broadway in Beechview is not congested and local residents requested retention of present access (1, p. X-7). The high labor cost of light rail in comparison with heavy rail is offset by greatly reduced feeder bus operations and less sophisticated fare collection but more revenue. The convenience of more frequent stops will result in slower main-line travel time over a specific route, but the retention of routes 35, 36, and 37 along Saw Mill Run Valley through Overbrook will offer time savings not offered by the other guideway alternatives. The short-turn opportunities offered by light rail also provide compensating economies.

Downtown distribution of passengers has always posed serious unsolved problems. For light rail service, the city of Pittsburgh suggested a division of service over three routing patterns:

1. Private right-of-way (including some existing railroad subway) east of Grant Street to the Penn Park Amtrak station opposite the Greyhound bus terminal (this alignment was common to all alternatives except the busway),
2. Exclusive transit lanes on Third and Fourth Avenues to serve an off-street terminal on county land at Smithfield Street (this would branch from the first alternative), and
3. Exclusive transit lanes on Smithfield, Oliver, and Wood Streets to Fourth Avenue to extend the second alternative closer to Gateway Center and major department stores (only one-third of the service would extend this far, and no multiple-unit trains would be permitted for fear of blocking cross streets).

With CBD route 1 (above) on the railroad alignment, no street operation would exist on the Saw Mill Run Valley line all the way to the outer termini [21 km (13 miles)]. The ridge-top route 42/38 would be traffic free as far as Broadway in Beechview [6.5 km (4 miles)]. Five suburban grade crossings would be separated. Unfortunately, however, most passengers would seek out the street service in the direction of the department stores and Gateway Center. The resultant operation--three outer routes, two short turnbacks, and three CBD options for each route--would not be practical. The headway between two specific points would be too long. It would be necessary to have a simplified service pattern to balance traffic by using a minimum of transfers at a common point, such as Carson Street.

A summary analysis of the four basic technological alternatives is given in Table 1 (1).

IMPLEMENTATION

After the completion of the alternatives analysis, the task force and the Port Authority board of directors unanimously adopted its recommendations. A draft environmental impact statement (EIS) was prepared and won the full endorsement of all major civic groups and agencies. Two individuals offered very minor objections (1, p. X-3). One person felt that any investment of any kind was hopeless.

Prior to the preparation of the EIS, a new city administration joined with county planners to express doubt about the use of exclusive rail lanes on downtown streets, where lack of capacity is perceived to be a serious problem. The success of a reserved bus lane on Fifth Avenue led nationally recognized consultants to suggest that the city convert Fifth Avenue to a light rail and pedestrian mall, but transit technicians had trouble finding a new location for the displaced buses and automobiles (1, p. V-128). Allegheny County had long wanted a short subway under Third and Fourth Avenues, instead of exclusive lanes, but this was felt to be too far removed from the city's activity centers. These varying ideas led to suggestions of a Fifth Avenue subway, but problems with geometry and sidewalk capacity caused the full-subway idea to be shifted to Sixth Avenue, a location that won unanimous endorsement and adoption after approval of the EIS.

Total removal of rail transit from the surface of CBD streets and the diversion of some bus travel to rail will result in higher bus speeds and added capacity for vehicle traffic.

UMTA has awarded, and the Port Authority has accepted, an initial or first-phase grant of $265 million for the Sixth Avenue subway, conversion of approximately 1.6 km (1 mile) of nearby railroad to transit use, extension of the system to South Hills Village, and rehabilitation of the trunk-line track, power system, stations, and other facilities on the 17-km (10.5-mile) line included in the original automated-guideway plan. New cars and the Mount Lebanon subway have been held for approval in the next phase, pending a comparison between Austrian tunneling methods and the more typical cut-and-cover methods. Route 35-Library service will not receive immediate major upgrading but will be given sufficient rehabilitation to keep it functioning.

OPERATIONS

The analysis determined that twice as many passengers will want to use the Sixth Avenue subway as will want to use the railroad alignment that will connect with the proposed East Busway for traffic-free service to the city's heavily populated East End. The busway is being designed with the option to extend the light rail service in that direction. A light rail operational pattern must be devised to split the service in proportion to demand and to load the cars evenly, with frequent headways.

The three basic outlying termini (Drake, Library, and South Hills Village) will be supplemented by two

Table 1. Economic comparison of four transit-system alternatives.

Item	Exclusive Busway	Transit Express-way	Heavy Rail	Light Rail
Guideway (km)	23.8	16.8	16.8	30.0
Stations and formal stops	46	12	12	54
Schedule speed (km/h)	29	40	40	32
Energy saving (MJ 000 000s)	1012	333.4	1263	1132
Passengers carried by year 2000 (000 000s)	39.5	39.5	39	40
Capital investment ($000 000s)[a]				
Construction	146.5	228.0	206.8	212.7[b]
Right-of-way	17.3	22.8	22.8	17.8
Rail vehicles	0	83.7	60.3	77.3
Buses	85.9	37.3	37.3	34.2
Engineering and administration	22.0	34.2	31.0	27.4
Contingencies	36.2	58.7	53.4	45.3
Total	307.9	464.7	411.6	414.7[b]
Annual operating costs ($000 000s)[c]				
Maintenance of way and structures	0.55	0.96	0.99	0.95
Maintenance of rolling stock	4.57	4.46	3.06	3.35
Energy (fuel or power)	1.61[d]	2.51	1.72	1.73
Conducting transportation	15.55	9.35	8.32	8.94
General and administrative	11.77	8.23	7.32	7.36
Total	34.05	25.51	21.45	22.61
Cost per passenger ($)				
Total operating cost	0.86	0.65	0.55	0.57
Capital recovery cost	0.70	0.94	0.84	0.83
Total	1.56	1.59	1.39	1.40[e]

Note: 1 km = 0.62 mile; 1 MJ = 947.8 Btu.

[a] 1975 dollars.

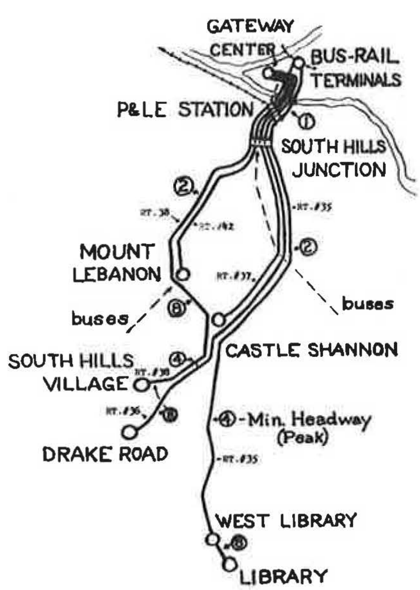
[b] Includes additional $30.2 million for Sixth Avenue subway, an improvement not included in the other options.

[c] 1975 dollars, including other services in corridor.

[d] OPEC and Iranian 1979 oil price and supply gyrations not reflected. Electricity in Allegheny County is predominantly coal fired, and there is some use of nuclear power.

[e] Includes cost of Sixth Avenue subway but reflects no saving from its operation. This saving is reported in the UMTA environmental impact statement (1, Table V-32, p. V-168) to be $100 000/year exclusive of surface traffic benefits.

Figure 3. Pittsburgh light rail transit routing proposal (peak-hour headways circled).



short turn-backs at Castle Shannon and Mount Lebanon. Library and Drake passengers are primarily home-to-work commuters. To speed their trip, these route 35 and route 36 cars should continue to follow the faster Saw Mill Run Valley route through Overbrook. Only one contraflow trip per quarter-hour should be scheduled to mitigate directional conflicts on the single track.

Figure 4. Golden Triangle showing proposed Sixth Avenue subway.

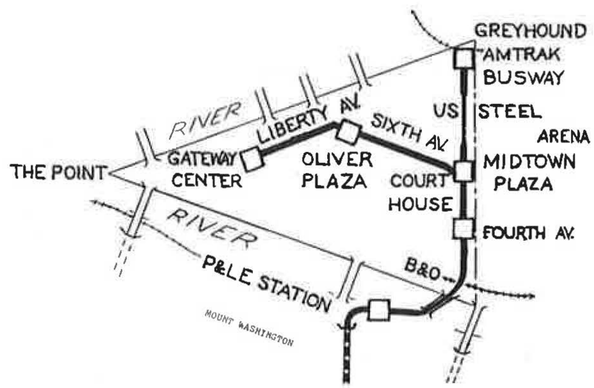


Table 2. Car requirements for initial operation of new system.

Route	To-From	Cars Peak	Cars Base
35-Library	Penn	23	5
36-Drake Road	Sixth Avenue	11	5
37-Shannon	Sixth Avenue	8	0
38-South Hills Village	To Penn during peak, to Sixth base	11	5
42-Mount Lebanon	Sixth Avenue	25	11
Schedule total		78	26
Spares and shop margin		10	62
Total		88	88

Additional reverse movements can follow route 42/38 to complete their round trip.

The South Hills Village Regional Shopping Center is expected to generate local traffic; this suggests that the South Hills Village service should follow the much more heavily populated route 42/38 through Mount Lebanon. The declining density of population with distance from the CBD suggests, and economics require, that a portion of the route 42/38 service turn back in Mount Lebanon near the present Clearview loop. Similarly, cars that carry passengers bound for the Linden Grove and Cretestone park-and-ride lots near Castle Shannon should not have to operate all the way to Library but should turn back at Castle Shannon (instead of short turning, outbound route 37-Shannon cars can become inbound route 42 cars and vice versa when single-track occupancy permits).

If the peak-hour common trunk headway were 1 min, the approximate service pattern would be as follows (see Figure 3):

Route	Headway (min) Peak	Headway (min) Base
35-Library via Valley	4	20
36-Drake via Valley	8	20
37-Castle Shannon via Valley	2	10
38-South Hills Village via Dormont	8	20
42-Mount Lebanon via Dormont	2	6.7

For route 37-Castle Shannon and route 42-Mount Lebanon, all available service is included in the headway, including routes from farther out.

When 1-min trunk headways are not adequate for the projected growth in travel volume, two-car trains will be used to avoid congestion. This is not feasible with the present PCC rail cars.

Express service on route 36 and on every other trip on route 35 is provided during peak hours and should be continued to minimize car kilometers while maximizing patronage.

At the CBD ends of the routes, studies anticipate a 3-min peak and a 20-min base headway to and from Penn Park Station and, as a result, 1.5-min peak and 5-min base headways in the new Sixth Avenue subway. Previous operation of 1-min headways in the Newark, New Jersey, subway (with four routes) and 27-s headways in Philadelphia's Woodland Avenue subway has established the practicability of very short headways with one-car trains, if multiple loading berths are used.

To offer this frequency of service, and the suburban frequencies specified above, it is most logical that route 35-Library and route 38-South Hills Village operate to Penn Park Station during the peak and only route 35-Library during the off-peak. All other service would use the Sixth Avenue subway to Gateway Center, which has an intermediate station near Wood Street in the heart of the shopping district near Oliver Plaza (Figure 4). This service pattern results in the car requirements given in Table 2.

The present fleet of cars will offer a one-way peak-hour capacity of 4680 passengers and a derivative all-day capacity of 28 000 (12 percent greater than that recently experienced). The resultant annual total will approximate 7.8 million passengers. Growing population, faster service, and new cars such as those Philadelphia and Toronto are purchasing, half operated in two-car trains and half as single units, would mean that 132 cars would be required to carry 7650 passengers one way in the peak hour. An eventual peak-hour total of 14 000 is projected, at which time two- and three-car trains will be required.

ECONOMICS

The alternatives analysis found that light rail service will save $9.5 million/year (in 1975 dollars) in comparison with the exclusive-busway alternative. The operational savings are even greater but are reduced somewhat by the added capital-recovery charges. Because of the excessive age of bridges and deterioration of facilities, new capital must be invested. Parallel highways are saturated at peak hours. Given the need and the commitment to upgrade facilities, the question of annual operating results becomes paramount. The Port Authority of Allegheny County currently budgets $85 million annually for transit expenses, of which 48 percent is recovered in revenues and 52 percent is covered by federal, state, and local subsidies that cover both bus and rail service.

The first-phase operation will use the present car fleet, which is undergoing rehabilitation. Annual cost estimates for this phase are calculated as follows (1 mile = 1.6 km):

Maintenance of way and structures = 46 miles x $18 000	$828 000
Maintenance of rolling stock = 93 x $10 000	$930 000
Power = 93 x $5400	$502 200
Platform labor = 108 x $21 000	$2 268 000
Supervision and administration at 16 percent	$754 800
Liability at 4 percent	$207 000
Annual total operating cost	$5 490 000
Annual passengers = 7.8 million at $0.57/passenger	$4 446 000
Loss ratio (loss ÷ cost)	19 percent
Operating ratio (Interstate Commerce Commission definition)	125 percent
Operating cost per passenger kilometer at 8.9 km/passenger	7.9¢

Excluding New York City, the typical domestic transit system has a loss ratio in excess of 50 percent and Interstate Commerce Commission operating ratios of more than 200 percent. The Pittsburgh transit system as a whole is quite typical in this regard. The upgraded light rail operation appears to have the capability of attracting and carrying more passengers at a much reduced percentage of loss. It may also be noted that the power system in Allegheny County is supplied largely from coal, not foreign oil. The initial 7.8 million passengers will consume 59.5 MJ (16.5 million kW•h) of electricity. If this were oil, including refinery losses, it would represent 4500 m^3 (1.2 million gal) yielding more than 15.3 passenger-km/L (36 passenger miles/gal), which is a 50 percent better yield than that of commuter automobiles. Because new rail cars use regenerative braking, almost 18.3 passenger-km/L (43 passenger miles/gal) is possible as compared with less than 13 passenger-km/L (30 passenger miles/gal) by automobile.

Data on the complete new system as it was envisioned by the consultants are given in the tables below [1 km = 0.62 mile; 1 MJ = 0.277 kW•h (electric power); 1 MJ = 947.8 Btu (energy)]:

Item	Amount
Guideway (km)	30
Stations and stops	54
Speed (km/h)	
Route 35-Library	28
Route 38-South Hills Village	25
Areawide system average	21
Electric power per year (MJ 000 000s)	151
Energy savings per year (MJ 000 000s)	286
Year-1990 light rail passengers (000 000s)	20.2

Item	Millions of Dollars 1975	1980
Capital investment		
Baseline plan construction	182.5	268.3
Sixth Avenue subway (net)	30.2	44.4
Right-of-way	17.8	26.2
Rail vehicles	77.3	101.7
Engineering and Administration	27.4	40.2
Contingencies	45.3	66.5
Total	380.5	547.3
Year-2000 annual operating cost		
Maintenance		
Way and structures	0.8	1.1
Vehicles	1.1	1.7
Energy	0.9	1.4
Conducting transportation	3.2	4.7
General and administrative	2.6	3.8
Total	8.6	12.7

Operating cost per passenger is determined to be 42.6 cents and 62.9 cents in 1975 and 1980, respectively. The following inflation rates were used in determining the 1980 dollar amounts given in the table: 6, 7, 8, 9, and 10 percent in 1975, 1976, 1977, 1978, and 1980, respectively. I have recalculated the 1980 capital investment for rail vehicles based on Southeastern Pennsylvania Transportation Authority light rail bids. Savings from the Sixth Avenue subway operation are included in the cost of conducting transportation and also in the 62.9-cent figure for 1980 operating cost per passenger.

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Planning Procedures for Transit-Station Renovation

JOHN R. GRIFFITHS AND LESTER A. HOEL

The application of planning and design procedures to the problem of transit-station renovation is described. The process is illustrated by using as an example the 69th Street Terminal in Philadelphia, a complex transit terminal that handles many transfer movements and transit vehicle connections and has a variety of system elements that are badly in need of renovation. The performance of the existing station was evaluated based on selected objectives and criteria and in light of its conformance with current policy guidelines. A series of alternative renovation layouts was produced to improve the processing of passengers by reducing conflicts, trip times, and level changes. These plans included consideration of horizontal and vertical separation, station access for fare collection, passenger volumes on each transit line, and accommodations for the disabled. Each alternative renovation plan was then evaluated along lines similar to those for the evaluation of the existing station. The results indicated the priority of each interest group and showed where conflict existed. The next step in the process is the preparation of detailed architectural and structural design plans and specifications, cost estimates, and a financial plan.

The renovation of transit stations is becoming increasingly important because the cost of new construction has been rapidly increasing while transit has been attracting new riders because of fuel shortages. Major capital investments in most new transit systems, such as those in Baltimore and Buffalo, are being built incrementally. In cities that have existing transit services, particularly Boston, Chicago, New York, and Philadelphia, greater reliance on present systems will be necessary. As newer systems begin to age, they too will be considered for renovation as recycling of transit structures becomes more productive and necessary.

Since the public's impressions and acceptance of transportation services depend heavily on the performance of modal interchange facilities, and since travelers generally place greater weight on time spent transferring between modes than on time spent in the vehicle, it is the abrupt transitions and delays at interface facilities that can reduce the service advantages offered by high speeds, frequent service, and advances in line-haul technology. In the case of older stations, these impedances are reflected in deficient designs, deterioration of physical plant, and changes in the public's perception of acceptable services.

This paper describes the application of planning and design procedures to the problem of transit-station renovation. The transit-station design process, as developed by Demetsky, Hoel, and Virkler (1), involves a series of procedural steps that assist the designer in ensuring consistency and comprehensive treatment in transit-station planning and evaluation. The methodology also uses analytic techniques, decision rules, and separate criteria for each interest group that uses the facility. Figures 1 and 2 illustrate the process. To demonstrate how the procedures are implemented, they have been applied to a complex station-renovation problem.

DESCRIPTION OF TRANSIT STATION STUDIED

The purpose of this study is to develop the planning process for transit-station renovation by applying each procedural step to an older, existing station that has deteriorated and is not functioning according to modern standards. The 69th Street Terminal just outside of Philadelphia was selected to demonstrate the planning process for transit-station renovation. This selection was based primarily on the station's need for renovation, the variety of system elements contained within the station complex, the availability of information, and the willing assistance of the agency that owns and operates the terminal [the Southeastern Pennsylvania Transit Authority (SEPTA)].

The 69th Street Terminal is located just north of West Chester Pike at its intersection with 69th Street. It is west of the city limits of Philadelphia in the township of Upper Darby in Delaware County and is the western terminus of the Market Street-Frankford subway-elevated line and the eastern terminus of a high-speed light rail line from Norristown. The station also serves two trolley lines and many bus lines that terminate in a well-established retail-commercial district in Philadelphia's western suburbs. Figure 3 shows the transit lines that are served by the terminal, and Figure 4 shows the terminal layout.

Approximately 50 000 persons/day (transit users and shoppers) pass through the terminal. In 1971, more than 70 percent of the daily subway-elevated users--about 13 200 persons--arrived at the terminal by means of public transportation. Of the 1200 daily users who drive, about 70 percent approach from either the West Chester Pike or Garrett Road. The morning and evening peak hours each account for about 30 percent of the daily users, or a total of 60 percent of daily traffic. The subway-elevated Frankford line operates 24 h and carries approximately 18 000 riders bound for the central business district (CBD).

The subway-elevated line operates six-car trains at headways from 3 to 30 min. The Norristown High-Speed Line is a light rail segment that uses single or tandem cars between the terminal and Norristown. The trolley lines to Media and Sharon Hill operate as single, low-level platform cars. Bus feeder service totaling 62 coaches in the peak hour is also provided. None of the rail lines are compatible or interchangeable with each other.

The terminal faces West Chester Pike, a major commuter route into the Philadelphia CBD. This arterial has a typical weekday volume of 25 000 vehicles and a peak-hour volume of 1100 vehicles in the peak direction. The terminal is located on a site of nearly 35 acres and consists of three inter-

Figure 1. Transit-station evaluation process.

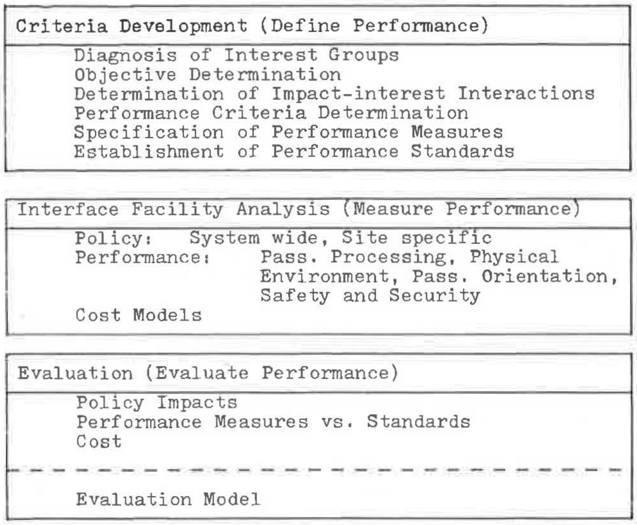
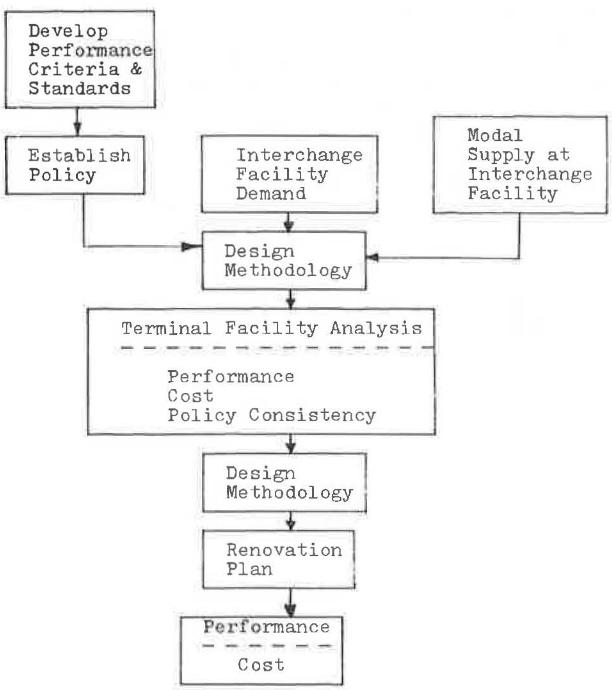


Figure 2. Transit-station renovation process.



connected structures: the old Philadelphia Transportation Company (PTC) building, the Red Arrow Suburban Bus and Tram Line building, and the Norristown High-Speed Line addition.

The PTC building, built in 1907, is the oldest structure and provides direct access from the West Chester Pike entrance to the high-level subway-elevated platforms situated below and behind its lobby. The Red Arrow building, constructed in the 1930s, is located adjacent to and west of the PTC building. Four platform areas serve both buses and trolleys. The Norristown High-Speed Line platforms are located in a structure that was constructed in 1963 to replace a 55-year-old "temporary" facility. This structure was an addition to the rear of the PTC building. It contains a stub-end, three-track, four-platform layout and has roofs over platforms only and an enclosed waiting room at the east end of the platforms. Access to the waiting room is provided from the lobby level of the PTC building and by stairs that ascend from the subway-elevated unloading platform.

The land that surrounds the terminal is urban in character. Lower- to middle-income homes dominate the area behind the retail outlets that line both sides of West Chester Pike and 69th Street. There are isolated commercial concentrations and some industrial development.

EVALUATION OF THE PRESENT STATION

The first step in the planning process is to evaluate how well the present station performs its required functions and to estimate the performance level that can be expected in the future if the station is not renovated. The present station is examined in terms of stated goals, objectives, and criteria and its conformance to SEPTA policy guidelines (e.g., the availability of restrooms and telephones). The results of the evaluation are depicted graphically on a factor profile diagram.

The basic goals set for transit stations by SEPTA are grouped as (a) architectural, (b) interchange function, (c) community related, and (d) transit. The objectives to be achieved by station renovation are grouped as (a) passenger processing, (b) environmental, (c) economic, (d) design flexibility, and (e) community. Each of the goals and objectives, and their interactions, is given in Table 1. For example, the architectural goal "to provide safety" is consistent with the environmental objective "to provide adequate lighting". In the analysis, it is the objectives that will be used to test the performance of the station because the goals represent general statements of system attainment.

The groups affected by transit-station changes are users, special users (such as the handicapped and the elderly), and operators. Since we are concerned primarily with the internal functioning of the station environment, the role of nonusers is not considered. The following table demonstrates how each of the system objectives (except community-related objectives) directly affects each of the interest groups:

Impact	User	Special User	Operator
Passenger processing			
Crowding	X	X	
Travel impedances	X	X	
Conflicts	X	X	
Disorientation	X	X	
Safety	X	X	X
Reliability	X	X	
Fare collection and entry	X	X	X
Level changes	X	X	
Physical barriers		X	
Emergencies	X	X	X
Environmental			
Ambient environment	X	X	
Lighting	X	X	
Personal comfort	X	X	
Aesthetic quality	X	X	
Services	X	X	
Weather protection	X	X	

Figure 3. Location of Philadelphia's 69th Street Terminal.

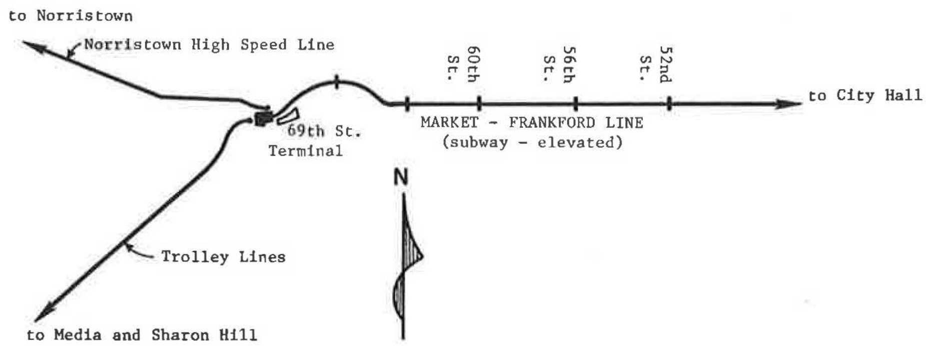
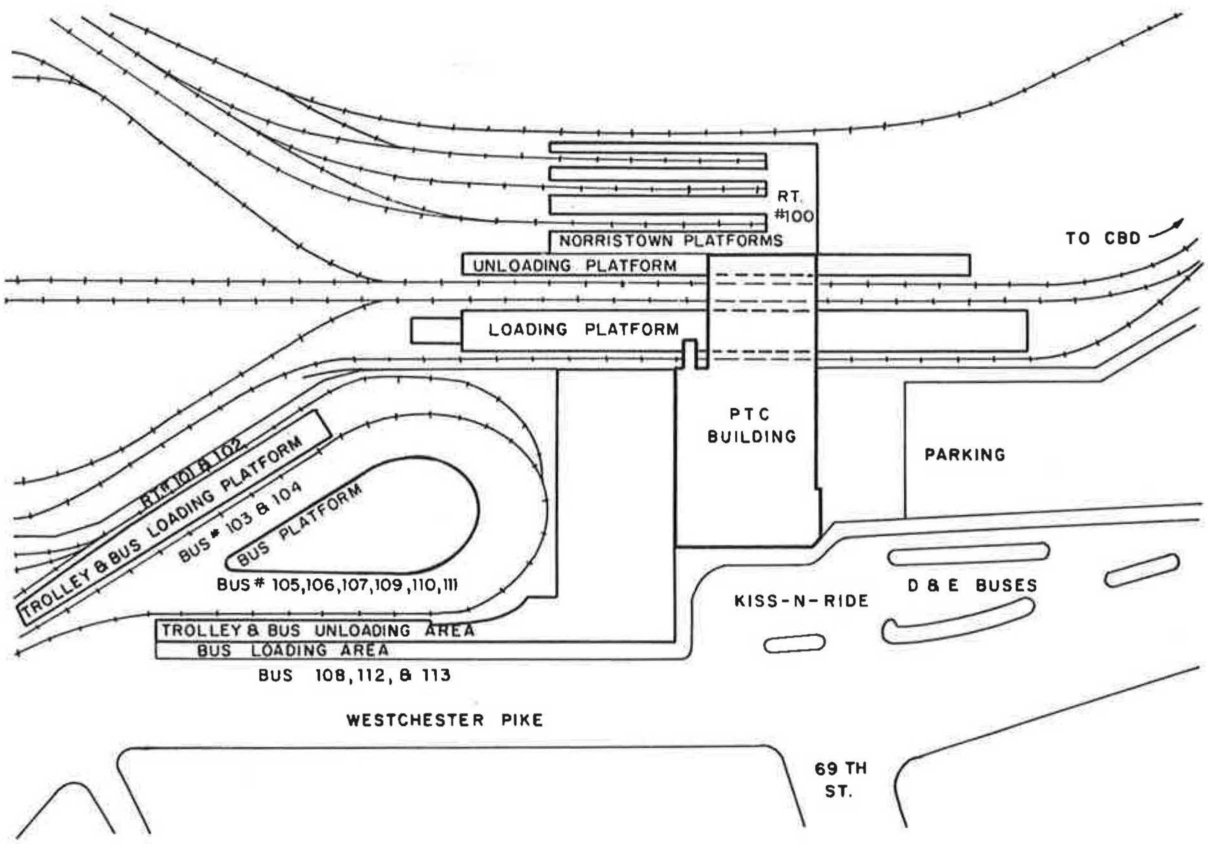


Figure 4. Layout of present 69th Street Terminal.



Impact	User	Special User	Operator
Security	X	X	X
Economic			
Costs			X
Income			X
Energy			X
Design flexibility			X

Clearly, users and special users are affected primarily by passenger processing and environmental objectives, whereas the operator is directly concerned with fare collection, safety and security, and economics and indirectly concerned with user satisfaction.

Finally, the criteria describe the performance measure that will be used to evaluate the station's performance for each objective. Table 2 gives several of the criteria and performance measures that were used in this study.

The present conditions at the 69th Street Terminal were evaluated for each of the objectives. Performance measures for each criterion were quantitatively calculated or qualitatively described. For example, to see how the station rates in terms of the objective of minimizing conflicts, the number of severe conflict areas was calculated. The procedures used to obtain each performance measure involve a lengthy process, and a detailed description of the process is beyond the scope of this paper (2).

The results of such an evaluation are summarized as a factor profile in Figure 5 for several criteria that apply to station users. These indicate the station performance for two periods: 1971 and 1985. Factor profiles as part of a decision-making process were used originally by Oglesby, Bishop, and Willeke (3) in evaluating freeway location alternatives. This method is selected because it includes all factors including those that cannot be stated in precise monetary terms. An estimate of degree of attainment is produced as the percentage of the max-

Table 1. Goal-objective matrix.

Objective	Goal: Provide Information	Provide Safety	Remove Barriers	Provide Convenient Transfers	Integrate Intersecting Lines	Reflect Community Character	Promote Mixed Station Use	Best Service at Least Cost
Passenger processing								
Minimize crowding			X	X				
Minimize travel impedances			X	X	X			
Minimize conflicts			X	X				
Minimize disorientation	X		X	X				
Maximize safety		X		X				
Maximize reliability				X				
Provide for efficient fare collection and entry control				X	X			
Minimize level changes			X	X				
Minimize physical barriers			X	X				
Provide for emergencies		X		X				
Environmental								
Provide comfortable ambience				X				
Provide adequate lighting	X	X		X				
Provide for personal comfort				X				
Provide aesthetic quality		X						
Provide supplementary services				X			X	
Provide protection from weather		X		X	X			
Provide adequate security				X		X		
Economic								
Minimize costs								X
Maximize net income							X	X
Use energy efficiently								X
Design flexibility					X		X	
Community								
Minimize impacts on local traffic						X		
Promote desired growth						X	X	
Minimize local disruption						X		

imum expected negative or positive effect of each factor. Where quantitative data are available, values are used that represent the limits of full attainment and nonattainment of objectives. For qualitative data, estimates of attainment were made according to SEPTA standards as well as subjective judgments.

Finally, the existing station is reviewed in light of its conformance with current policy guidelines. For example, if the managing agency's policy is to require telephones in the station, the present facility is rated in accordance with this policy. It was found that the station failed to meet policy guidelines in the areas of placement of advertising signs, aesthetics (art, music, and landscaping), construction materials, passenger orientation, and safety. Policy guidelines were partly met for security, personal care facilities, parking, and provisions for special users. The station was noted to be in conformance with policy in the provision of concessions and services, telephones, and the physical environment (the station areas are enclosed, although not climate controlled). Attention to the items identified as deficient could result in a significantly improved station without the need for extensive redesign of the station layout.

GENERATION OF ALTERNATIVES

Each of the alternative station-renovation plans developed for evaluation will involve the rebuilding of the station's interior, the realignment of platforms, and other structural changes. The plans were selected because of their potential for reducing walking distances, minimizing conflicts, and consolidating bus platforms. Other considerations that led to layout modifications were the need for improved weather protection, for a logical layout, and for long sight lines and high ceilings to facilitate surveillance.

A brief description of each alternative is given below:

1. Alternative 1 (see Figure 6) retains the present terminal layout. Minor relocations and modifications are provided for bus platforms and taxi and kiss-and-ride areas. The entire terminal is upgraded to the quality of a new station. The capital cost is $3.1 million.
2. In alternative 2 (see Figure 7), the aboveground building portion of the bus circle area west of the original subway-elevated structure would be removed. The platform arrangement for taxi, bus, and kiss-and-ride areas is changed. The ramp from the West Chester Pike bus platform to the main ramp is closed. A level corridor from the bus platform to the subway-elevated main corridor is added, thus eliminating two level changes and reducing congestion on the present ramp. The capital cost is $2.4 million.
3. In alternative 3 (see Figure 8), bus platforms in the center of the bus and trolley circle are removed, thus eliminating two-way traffic. Most bus routes would discharge passengers directly in front of the terminal. The western section of the subway-elevated is removed, and the taxi and kiss-and-ride areas are relocated between the subway-elevated and the parking lot. The cost is $1.9 million.
4. In alternative 4 (see Figure 9), much of the present terminal is removed and a new section is constructed over the subway-elevated tracks. Sections of the terminal described in alternative 3 are removed, as is the subway-elevated lobby. Elevated corridors are provided to all bus platforms, and the taxi area is relocated. The estimated construction cost is $2.9 million.
5. In alternative 5 (see Figure 10), all passenger-terminal structures between West Chester Pike and the subway-elevated tracks are removed. The trolley loop is placed below grade at the elevation of the subway-elevated line. Bus platforms are constructed at street level above the trolley loop. A new addition to the present structure spans the subway-elevated alignment. The taxi areas and bus area are located together, and the kiss-and-ride area is

located between the bus unloading area and the parking lot. The estimated construction cost is $4.4 million.

EVALUATION OF ALTERNATIVE RENOVATION PLANS

The evaluation of each of the alternative renovation plans outlined above follows the procedure used earlier. For each criterion for which significant differences in performance are noted, a performance measure is obtained. These are plotted on a factor profile for each interest group. The factor profile is used to establish a dominant alternative and to carry out a trade-off analysis when one alternative is not dominant in every category.

The following discussion illustrates the result from the user's viewpoint and how the trade-off analysis produces a selected plan. Figure 11 shows the factor profile for these conditions (the numbers in circles represent the degree of attainment of the various alternatives).

In a comparison between alternatives 1 and 2, alternative 2 is superior to 1 in almost every category. It provides a slight improvement in station aggregate walk time and conflict, lessens the complexity of path choice, and provides a more unified visual theme.

In a comparison of alternatives 2 and 3, both have advantages. Alternative 2 is favored because it is slightly less complex and safer (because of fewer stairways), requires fewer level changes, and provides more concession space. On the other hand, alternative 3 requires less walking, reduces conflicts, eliminates exposed platform areas, and has more observable space. Since some of the advantages of alternative 2 make it only slightly better than 3 whereas those in which alternative 3 excels are quite significant, alternative 3 is more desirable from the user's point of view.

In a comparison of alternatives 3 and 5, alternative 5 dominates alternative 4 and thus alternative 4 is eliminated from consideration. Analysis of the positive attributes of each alternative would indicate that users prefer alternative 5. Among the advantages of this alternative are reduced walking time, elimination of conflicts, fewer level changes, enclosed platforms, and a unified architectural theme.

A similar analysis of the alternative plans was carried out for special users and operators. The preferred alternatives are given below:

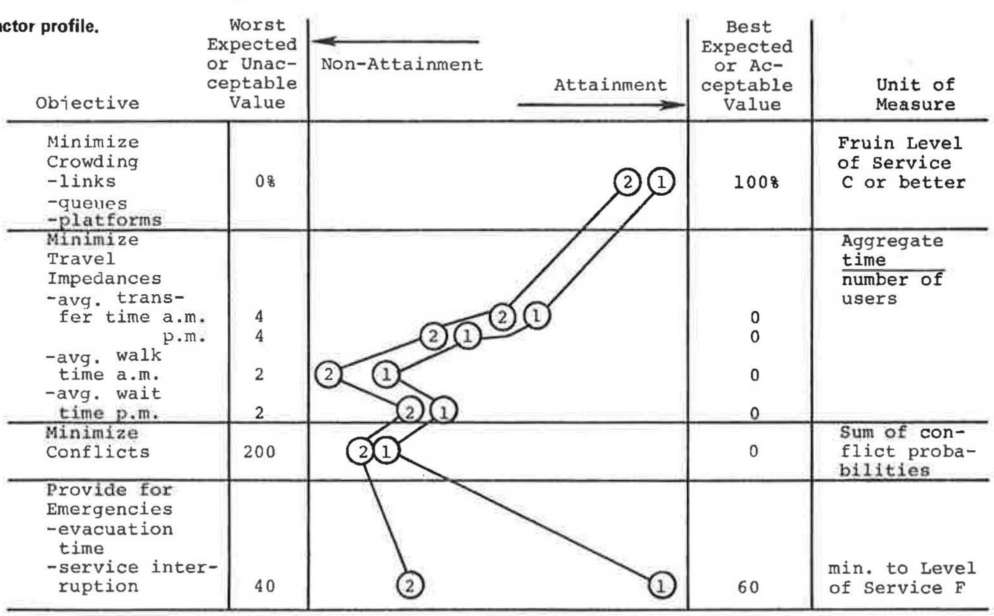
Group	Preferred Alternative Versus Second Choice
User	5 versus 3
Special user	5 versus 3
Operator	3 versus 4

The selection of alternative 3 by the operator is largely influenced by the cost involved: Alternative 3 costs $1.9 million, whereas alternative 5 costs $4.4 million. Since alternative 3 is the second choice of both users and nonusers, it will probably be selected. If alternative 3 were not a possible compromise, other situations would be examined until a final plan was reached.

Table 2. Relations among selected objectives, criteria, and performance measures.

Objective	Criterion	Performance Measure
Minimize crowding	Fruin level of service	Percentage level C or better
Minimize travel impedances	Path walk times	Minutes per path
	Path wait times	Minutes per path
	Aggregate walk time	Person minutes
	Aggregate wait time	Person minutes
	Aggregate transfer time	Person minutes
	Average transfer time	Minutes
Minimize conflicts	Fruin probability of conflict	Number of severe conflict areas
Provide comfortable environment	Thermal conditions	Temperature and humidity
	Noise level	dB(A)
Provide adequate lighting	Illumination level	Footcandles
Minimize costs	Capital cost	Dollars
	Operating cost	Dollars per year
	Maintenance cost	Dollars per year
Minimize impacts on local traffic	Additional delays	Person minutes
	Additional accidents	Increase in accident rates

Figure 5. User factor profile.



NOTE: Attainment values are given only where there is a significant difference between 1971 (1) and 1985 (2) values.

Figure 6. Plan view and elevation for alternative 1.

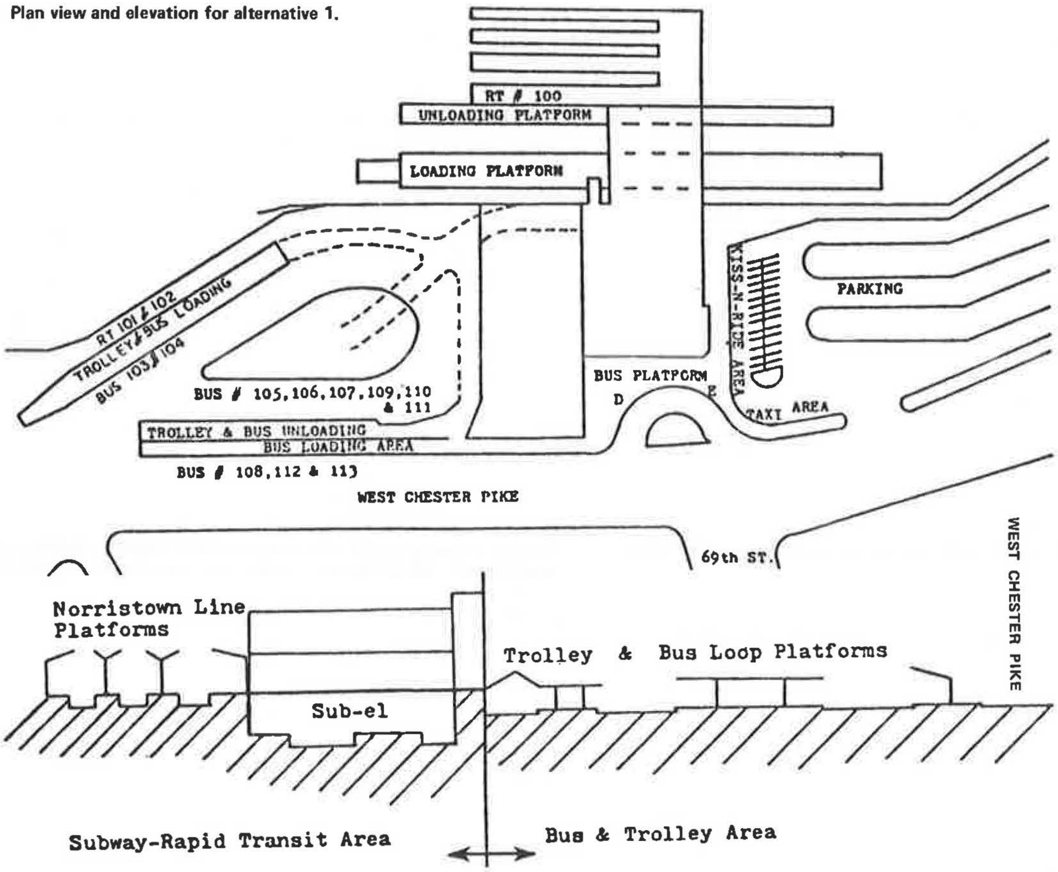


Figure 7. Plan view and elevation for alternative 2.

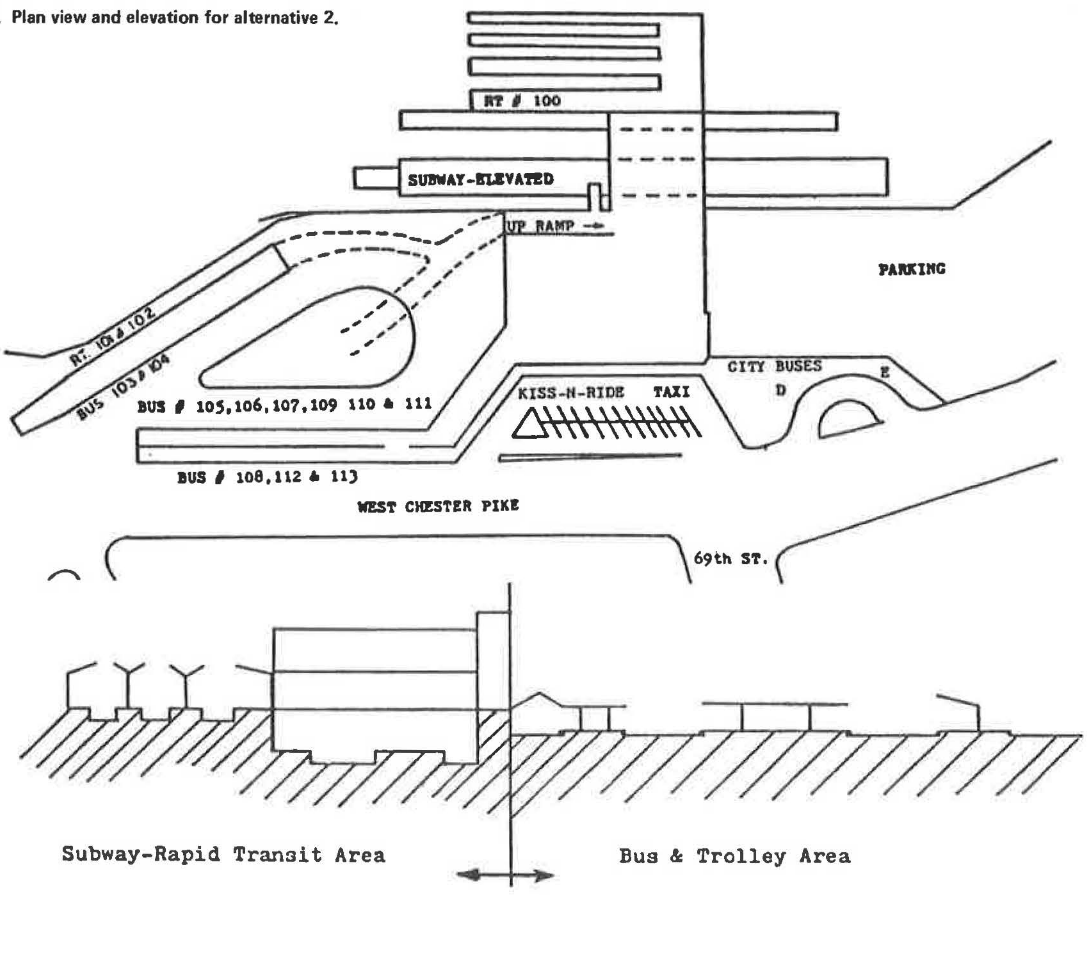


Figure 8. Plan view and elevation for alternative 3.

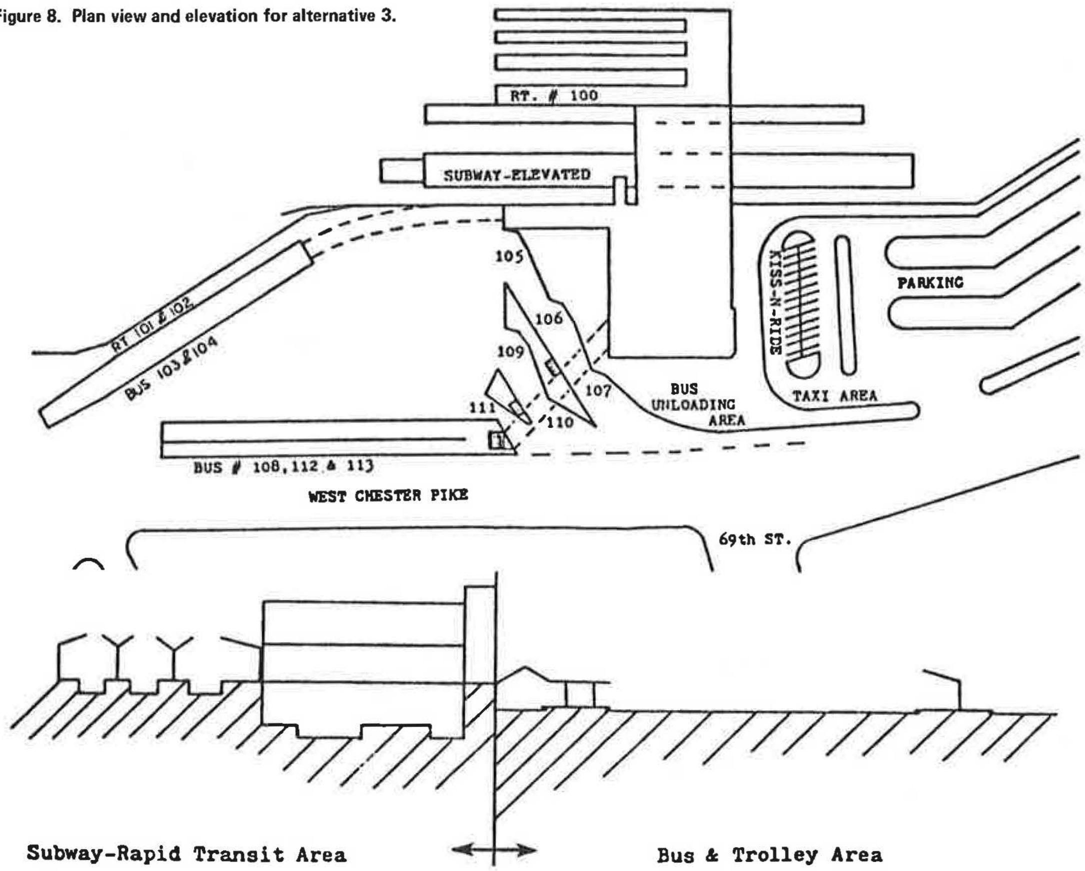


Figure 9. Plan view and elevation for alternative 4.

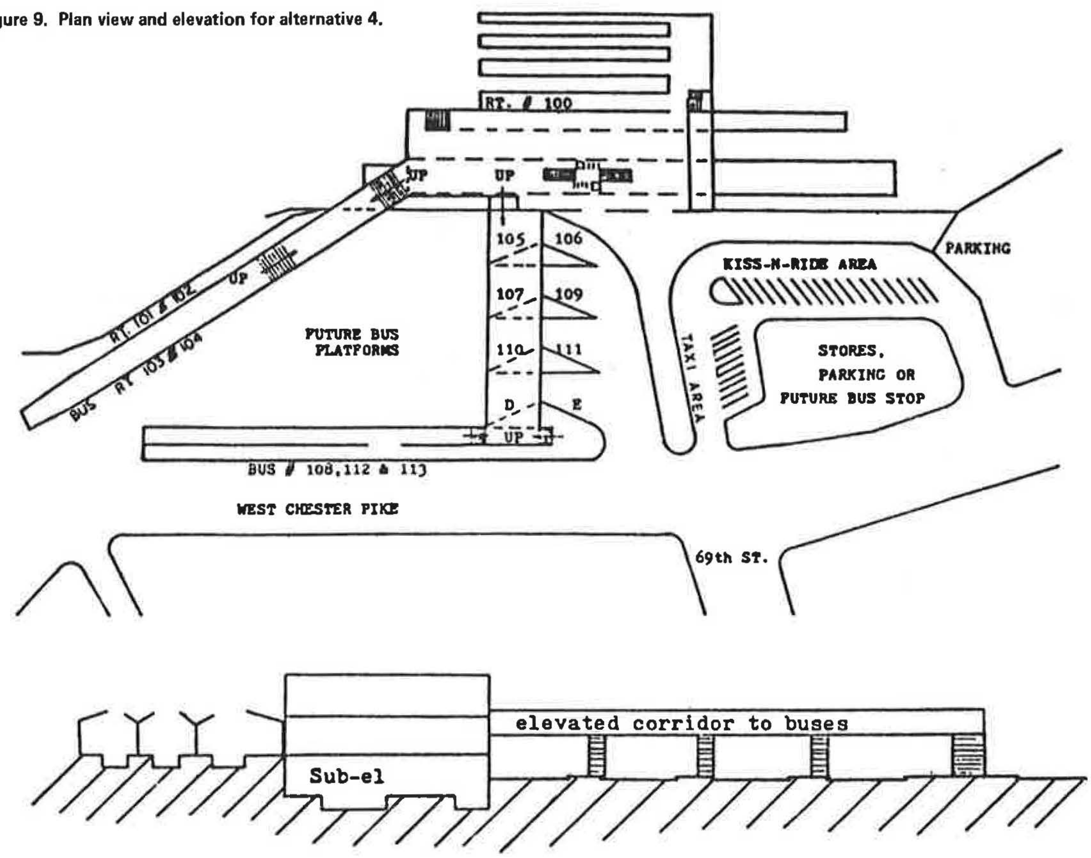


Figure 10. Plan view and elevation for alternative 5.

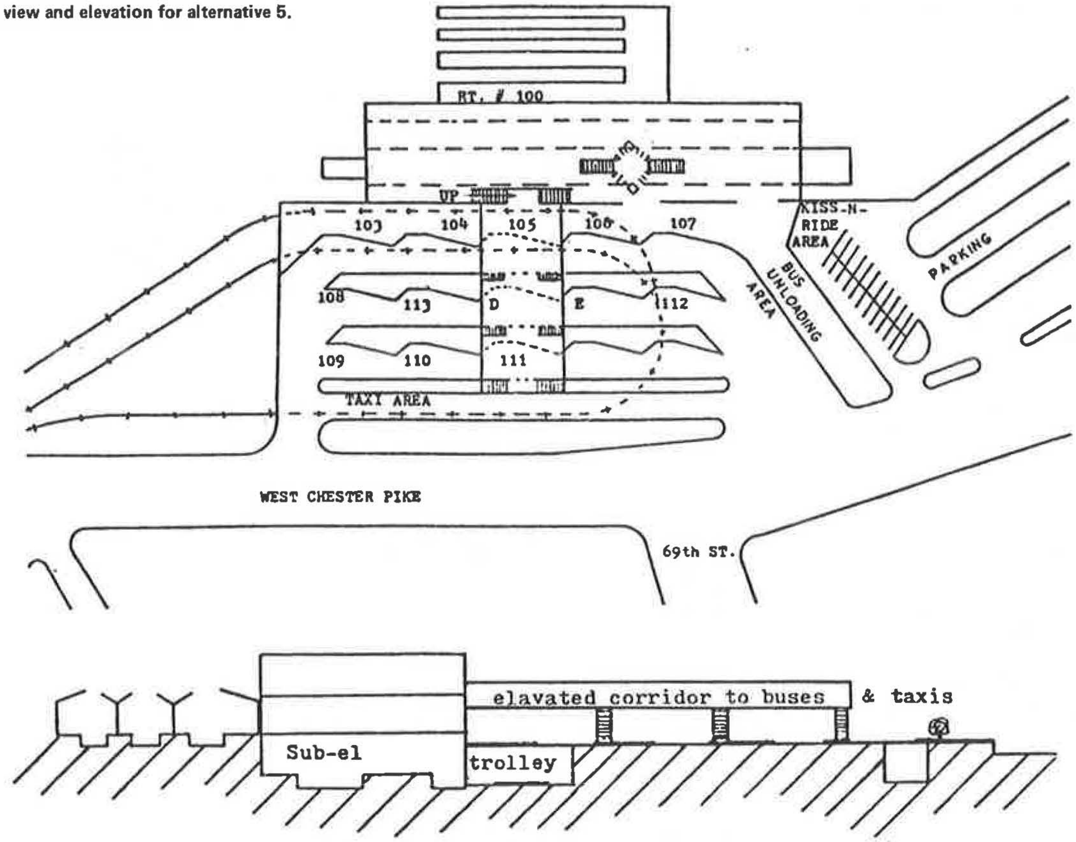
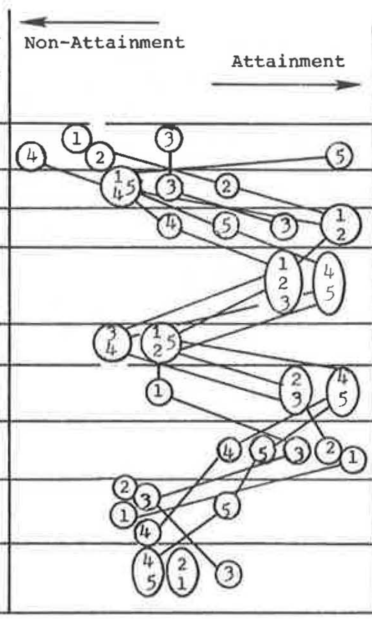


Figure 11. User factor profile for five alternatives.

Objective	Worst Expected or Unacceptable Value	Best Expected or Acceptable Value	Unit of Measure
Minimize Travel Impedances	9,000	4,000	aggregate walk time min.
Minimize Disorientation	10	1	Maximum D_{ij}
Maximize Safety	--	--	Descriptive
Provide for Efficient Fare Collection and Entry Control	--	--	Descriptive
Minimize Level Changes	5	0	Changes per path
Provide Aesthetic Quality	--	--	Descriptive
Provide Supplementary Services	--	--	Descriptive
Provide Protection from Weather	100% Open	100% Fully Enclosed	% fully % part % open
Provide Adequate Security	0%	100%	% area in view of attendants



REFINEMENT OF SELECTED PLAN

After the basic renovation plan has been selected, modifications are considered that will further refine the design. Among the elements considered are (a) reducing delays and movement conflict in the subway-elevated corridor, (b) reducing evacuation time, (c) accommodating additional bus stops, (d) improving turnstile and door reliability, (e) reducing transit noise, and (f) improving station orientation.

After the station-renovation plan is completed, detailed architectural and structural design plans and specifications, as well as detailed cost and finance estimates, must be prepared. A detailed construction plan that describes the staging of the work and the provisions required to maintain transit service during renovation is also required. The required provisions could include the rerouting of buses to other stations along the subway-elevated line. These would be undertaken if the project were selected for renovation and funds were allocated by the agency.

SUMMARY

The process for selecting a renovation plan for transit-station improvement has been described and illustrated by using a complex urban terminal facility. The process involves the establishment of goals, objectives, and criteria for each affected interest groups and evaluation of the existing terminal in terms of its performance and present policy. Alternative station layouts that improve movement patterns, reduce conflicts, and limit walking are developed. Each alternative is evaluated from the viewpoint of the interest groups affected, and the results are depicted in a factor profile diagram. Dominance and trade-off analysis are used to select an alternative for implementation.

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Joint Development Around Intermodal Transfer Facilities

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Efforts undertaken in the city of Baltimore to initiate joint development around transit stations are examined. Under the provisions of the 1974 amendment to the Urban Mass Transportation Act of 1964, the U.S. Department of Transportation could make grants or loans for the establishment of transit corridor development corporations and for the purchase of land and the development of property adjacent to transit stations. Baltimore was one of the first cities to apply for funds under the new legislation. Although the Urban Mass Transportation Act of 1964 has since been amended to remove specific authorization for the funding of transit-corridor development corporations, the Urban Initiatives Program, established in 1979, provided funding for the Baltimore program. The key factors underlying the successful development of the Baltimore program are identified. Specific joint-development projects are examined, and the main points of the joint-development application are discussed. Observations are offered on the nature of contemporary joint development and the involvement of the public sector.

A fundamental premise of the Urban Mass Transportation Act of 1964 is that mass transportation systems are required for desirable urban development. Yet new rapid transit systems have not fulfilled their promise of inducing beneficial urban changes. These changes can be implemented if transit planning and land use planning are linked and are strengthened by the authority and resources to implement land development. This was the impetus behind enactment of the 1974 Young Amendment to the act, which provided for federal funding of transit corridor development corporations (TCDCs).

Since the 1974 amendment, only a handful of cities have taken steps to obtain Section 3 grants (discretionary capital grants) for use in setting up TCDCs. Among these, Baltimore is the closest to receiving funding. Portland (Oregon) and Denver are also likely candidates. A number of other cities have undertaken preliminary joint-development studies and, under a grant from the Urban Mass Transportation Administration (UMTA), the Rice University value-capture team has studied several cities (1,2).

This paper examines the efforts undertaken in Baltimore to initiate joint development around several stations planned for the first section of the regional rail rapid transit system now under construction. Factors contributing to the joint-development program are discussed, and the history of the Baltimore effort is described. The organizational framework within which the joint-development plans were developed is discussed, and the joint-development application and constituent project plans are presented. The paper attempts to identify the key factors for a successful joint-development project. It is recognized, however, that each project is unique and no universal conclusions can be drawn from only one example. The paper concludes with some observations on the nature of contemporary joint development and the role of the public sector.

FACTORS LEADING TO JOINT DEVELOPMENT

The major factors that led to the joint-development projects undertaken in Baltimore can be summarized as follows:

1. A rail rapid transit system was already being built.
2. Baltimore was actively pursuing urban

development programs administered by a strong city agency, the Department of Housing and Community Development (HCD), which had already started two quasi-public corporations.

3. Baltimore's retail district was declining, and a study prepared by a consulting firm had pointed out the need for pedestrian connections and also developed a joint-development plan for the Lexington Market transit station.

4. The Baltimore Regional Planning Council (RPC) received funding from UMTA to study transit-station-area development and access. Local jurisdictions prepared most of the development planning for that study.

Baltimore Mass Transit System

The most obvious and crucial factor in the series of events outlined above was that a rail rapid transit system was being built in Baltimore. The completed system will cover three jurisdictions: the city of Baltimore, Baltimore County, and Anne Arundel County. Regional planning for the transit system was conducted by the RPC and coordinated with the three jurisdictions.

Initial planning, which began in 1961, envisaged a 65-mile regional system with six radial corridors. The original system (phase 1) was to be 28 miles in length. Of this initial system, an 8.5-mile segment known as the Section A line has been financed and is under construction. The Section A line, budgeted to cost $721 million, is expected to be in operation by 1982 with an average daily patronage of 83 000 riders. A map of the Section A line and its station locations is shown in Figure 1.

Section A is being constructed by the Mass Transit Administration (MTA) of the Maryland Department of Transportation (DOT) and is being financed through an UMTA capital grant. The local share of the grant is provided, by means of a state gasoline tax, from state transportation funds. Funding for the remainder of the proposed system is uncertain.

The next segment to be built will probably be the extension of the Section A line through Baltimore County to Owings Mills. This paper focuses on Section A transit-station joint-development projects.

Active City Development Programs

A second major contributing factor in the Baltimore joint-development projects was the city's active urban renewal and community development programs and the political composition of the city that made these programs possible. A municipal organizational chart that clarifies the role played in the joint-development projects by city departments and officials is shown in Figure 2 (3).

The key positions can be outlined briefly as follows. The mayor, the chief executive of the city, has the power to veto ordinances passed by the City Council and to appoint municipal officials. These appointments, which are subject to City Council approval, include city department heads as well as members of boards and commissions that govern city agencies. The mayor has the power to appoint "special agents"--in effect, to establish new offices or appoint coordinators who can transcend departmental limitations.

The Board of Estimates determines the city's fiscal policy. It consists of the mayor, the city solicitor and the director of public works (both appointed by the mayor), the comptroller, and the president of the City Council (the latter two posts filled by election at large).

The City Council is a single-chamber legislative body consisting of 18 members (elected from districts) plus the president. The City Council votes on ordinances and resolutions.

The Planning Commission, a nine-member body appointed by the mayor, is charged with the oversight of the Baltimore Planning Department. The Planning Department prepares Baltimore's comprehensive plan, which is then adopted by the Planning Commission. The plan contains a one-year capital budget and a six-year capital development program for all proposed physical development in the city. The plan includes the location and extent of public improvements, such as subways. The Planning Department is organized into several areas: commission services, area planning, citywide systems planning, facilities planning, design services, and support services. When the transit system was in the planning stages, the Planning Department studied the land use impacts of the transit system, including the consideration of joint development. The Planning Department has cooperated with other agencies in preparing transit-station joint-development planning concepts.

The HCD builds and manages public housing; enforces the housing, building, and zoning codes; and carries out urban renewal and community development programs. The HCD contains several divisions: administration, construction and building inspection, home ownership development program, housing management, information services, land development (in urban renewal areas), neighborhood development, relocation, resident family services, and planning (for urban renewal areas).

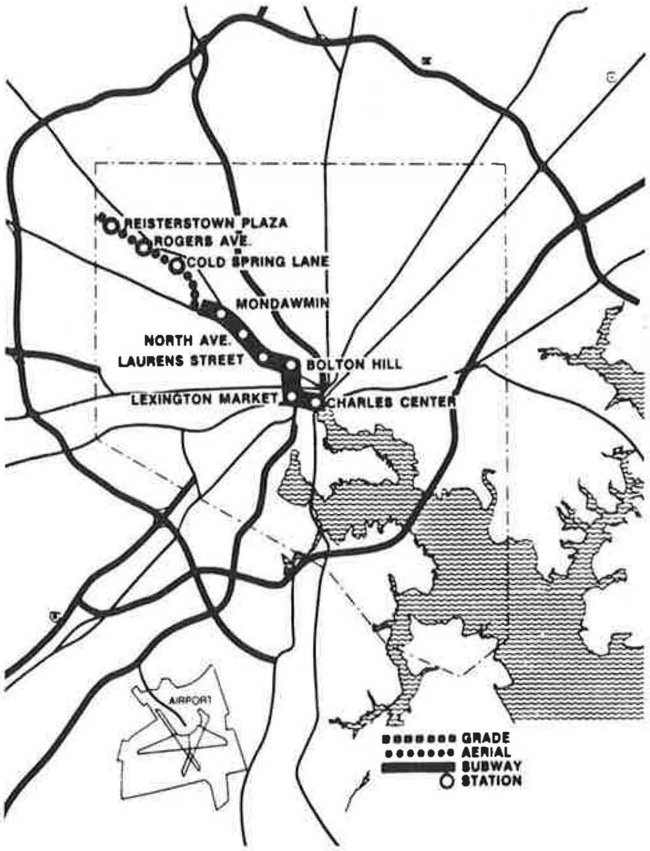
The HCD, an active department, has already sponsored two quasi-public development corporations. Charles Center-Inner Harbor Management, Inc., is concerned with downtown development, and the Baltimore Economic Development Corporation deals with industrial development. Because the land around each transit station in the proposed system was declared an urban renewal area by the city, this land falls under the jurisdiction of the HCD. The HCD has been instrumental in the evolution of joint development around transit stations in Baltimore.

Joint development requires cooperation between the public and private sectors and within the public sector as well. The formal organization of the city has been described. However, the actual nature of the cooperation and the informal links between the mayor and the various departments cannot be described in an organizational chart. These informal links evolved over time out of the formal structure.

As noted above, the first segment of the rapid transit system is being built entirely within the city of Baltimore by the MTA, a state agency. For the planning and construction of the line, it was necessary that the MTA cooperate with the city and its departments. In Baltimore's "strong mayor" form of government, the mayor has the power to appoint municipal officials. One such appointed official, the mayor's physical coordinator for transportation, was also, at the time that construction of the transit system began, the HCD commissioner. Under this authority, a transit task force was established to serve as a liaison betwen the MTA and the city and its departments. The transit task force was to deal with problems in the construction of the transit system within the city of Baltimore.

The transit task force was composed of two former HCD employees, who were paid through contracts with HCD. When the offices of physical coordinator for transportation and commissioner of HCD were no

Figure 1. Section A of Baltimore rapid transit system.



longer held by the same person, the members of the transit task force remained contractual employees of HCD. While the transit task force was to deal with the construction of the transit system, it also became involved in the joint-development projects. The members of the task force, as former HCD employees, had been active in the Charles Center-Inner Harbor projects. They had also been staff members on the city's Retail District Study.

Declining Retail District

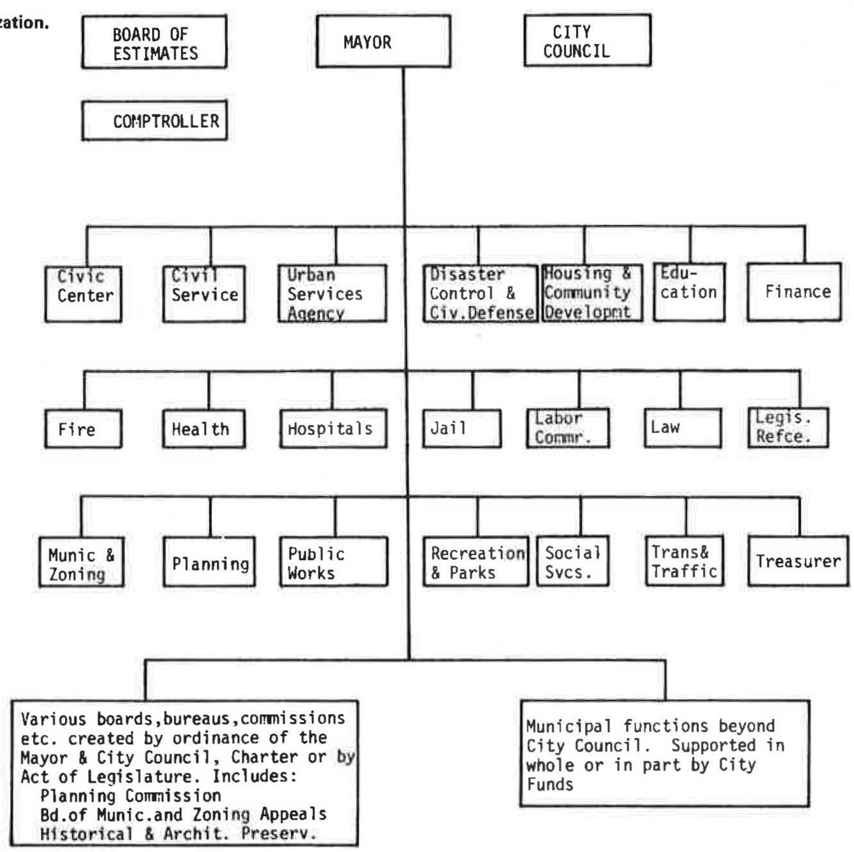
The Retail District Study was established in 1974 to examine Baltimore's declining downtown retail district. The Retail District Executive Committee included the Retail Merchant Association, the Greater Baltimore Committee (GBC), and city staff members. The main thrust of the study was provided by the GBC. Founded in 1954, this committee is composed of business interests concerned with the vitality of downtown Baltimore. The GBC actively supported the Charles Center-Inner Harbor projects and then began to focus on the declining retail district.

In 1974, the Retail District Executive Committee hired Arthur, Cotton, and Moore and Associates as consultants to study the retail area and propose solutions. The study called attention to the need for pedestrian connections to link the retail area to other areas in the city. The study also pointed out the potential for joint development and fostered the concept of Baltimore Gardens, a joint-development project around the Lexington Market station.

Transit-Station-Area Development and Access Study

The idea of joint development around the Lexington

Figure 2. City of Baltimore municipal organization.



Market transit station (i.e., Baltimore Gardens) gave impetus to the planning for all stations and to the application for UMTA funding under the 1974 Young Amendment. However, this was not the only factor. When the transit system was being planned, the Planning Department had looked at the land use impacts of the proposed transit system. The planner who had been in charge of the Baltimore city impact study attempted to secure funding to look more closely at the station areas in the light of joint development. In 1970, he began an application process to obtain UMTA funding to study the stations. Inasmuch as the transit system was a regional system, UMTA felt that the application should involve study of the station areas of the entire system and should be coordinated by the designated metropolitan planning organization, the RPC.

In 1974, funds from the state of Maryland and UMTA were committed to the Regional Planning Council for the comprehensive Transit-Station-Area Development and Access Study (TSADAS), which considered all stations of the rapid transit network. This study was part of a unified transportation planning process that outlined the duties of, and coordination between, the city of Baltimore, Anne Arundel County, Baltimore County (the three local jurisdictions), the Maryland DOT, the MTA, the state highway administration, and the RPC. The RPC worked with the three local jurisdictions to develop "policies and guidelines for transit-related development in station areas included in Phase I of the Baltimore Rapid Transit System" (Section A line) (4). Each jurisdiction prepared data and planned development for stations within its boundaries.

Thus, the city used TSADAS funds to plan development around the transit stations. The Baltimore Gardens concept for the Lexington Market station had already been prepared by Arthur, Cotton, and Moore and Associates in conjunction with the HCD. The Planning Department studied the remaining stations, developed station-area profiles, and also explored joint-development possibilities for these stations.

Application for UMTA Joint-Development Funds

Out of a combination of these factors emerged Baltimore's plans for joint development around three transit stations: Lexington Market (Baltimore Gardens), North Avenue, and Reisterstown Plaza. Other transit stations, such as the Cold Spring station, have joint-development possibilities but were not included in Baltimore's application for UMTA funds. Plans for the three stations selected for joint development were the result of a combination of efforts by the consultants who worked on the Baltimore Gardens concept, the TSADAS work team (primarily planners from the city Planning Department), planners from the HCD urban renewal planning division, and the transit task force.

Baltimore applied for Section 3 UMTA funds to develop the three stations. The decision to submit the application was made in September 1976, and the application was filed in January 1977. A study of the environmental impact of the three stations is expected to be completed around September 1978.

Baltimore was among the first cities to apply for, and will probably be the first city to receive, Section 3 UMTA funding. The funding request for the projects is outlined below (5, p. 9a):

Project	Funds Requested ($000 000s)
Lexington Market station (Baltimore Gardens)	7.0
North Avenue station	0.9
Reisterstown Plaza station	0.9
Formation of TCDC (for six years at $200 000/year)	1.2
Total	10.0

Baltimore's application for UMTA funds includes a request for $1 200 000 for the formation of a TCDC. This corporation would be a public-private partnership under the guidance of the HCD. As mentioned previously, the HCD currently guides two such quasi-public corporations (5).

The table above indicates that the Baltimore Gardens project constitutes $7 million of the $10 million UMTA request. A breakdown of the funds requested from UMTA is given in Table 1 (5). Construction costs for 100 000 ft^2 of retail space and 60 000 ft^2 for entertainment purposes, at $40/$ft^2$ (approximate total $6.4 million), have not been requested to be paid by the UMTA grant (5).

Lexington Market Station

Baltimore Gardens would consist of a combination of new retail and entertainment development intermixed with a public garden and a park. Pedestrian connections are planned between the nearby transit station, at Eutaw and Lexington Streets, and the new development and park and already existing stores. This concept was possible because one of the department stores on the corner of Howard and Lexington Streets went out of business (nationwide), thereby freeing the land for possible new construction. The planning context and site plan are shown in Figure 3. The area has a 23-ft slope down Lexington from Eutaw to Howard. If the site is excavated, therefore, a three-level transit station with pedestrian connections at each level is possible. The subway mezzanine level would be fed by Lexington Mall, the middle retail level would connect to Lexington and Saratoga Streets at midblock, and the upper level would be Eutaw Street (5). The three levels are shown in Figures 4-6.

North Avenue Station

The North Avenue station is located in a declining low-income residential neighborhood. Projected station development would include a new station entrance and pedestrian connections to a proposed high-rise housing unit for the elderly, with convenience retail shops on the main floor. A breakdown of the UMTA funding request for this station is given in Table 2 (5).

The success of the North Avenue station development hinges on the proposed high-rise housing unit for the elderly. This unit would contain 260 one-bedroom apartments, for which rental would run about $350/month. The housing would be financed by funds from the U.S. Department of Housing and Urban Development (Section 8), the Federal Housing Administration, and the Maryland Department of Economic and Community Development (5).

Reisterstown Plaza Station

The Reisterstown Plaza station is to be located near a regional shopping mall. The new development would consist of pedestrian connections and a publicly developed pedestrian route linking the transit station, a nearby railroad station, and the shopping mall. Office and retail sites along the pedestrian route will be made available to private developers. The development site is currently vacant land except for one vacant single-story structure (5). The key issue in the area is to coordinate any new development of the vacant land with the transit station. The breakdown of the UMTA funding request for this station is given in Table 3 (5, p. 30).

COORDINATING JOINT DEVELOPMENT

Joint development demands coordination among many agencies, at various levels, in both the public and private sectors. In Baltimore, coordination was necessary among (a) private-sector interest groups and local community groups, (b) the developer, (c) the mayor, (d) city departments, (e) the transit authority, (f) the regional transportation agency, (g) the RPC, (h) the state DOT, and (i) UMTA and other federal agencies. To achieve the required coordination in such a project, there must be some person or agency that is able to (a) maintain an overall view of what is going on in the city and the region, (b) make policy or have access to policy-makers, and (c) work with UMTA, the state DOT, the transit authority, and the developer.

In Baltimore, the high level of coordination necessary for successful implementation of joint development was provided through the HCD. The head of the HCD had direct access to the mayor, and the department possessed powers broad enough to maintain a wide scope on the project. The initial, informal coordination of the project by HCD was formalized, as the project moved ahead, with the creation of the transit task force.

The important factors to note are that the timely implementation of joint-development projects should involve the use of techniques familiar to the city and should be done through familiar channels. This is especially pertinent in public-private ventures because time is an important cost factor in private developments. Wherever possible, the agency with the best track record of success should be used.

Table 1. Funding request to UMTA for Baltimore Gardens station.

Item	Cost ($000s)
Land preparation	
Business relocation	484
Land acquisition (69 750 ft^2)	4288
Demolition of existing structures and site preparation	640
Public area development and pedestrian connections	
Plaza construction (32 750 ft^2 at $\$20/ft^2$)	655
Upper-level public walkways	160
Glass coverings	328
Plantings and furniture	50
Vertical circulation and connections	395
Total	7000

CONCLUSIONS

During the past several decades, entrepreneurs and real estate developers have been quick to take the initiative in acquiring land around highway interchanges and airports. Prior to the large-scale involvement of government in the construction of highways, when large-scale railroad and streetcar systems were being constructed, the transit companies themselves often acquired, developed, and sold the land adjacent to their rights-of-way. Suburban housing, downtown commercial centers and railroad stations, and even amusement parks at the ends of trolley lines are all manifestations of the well-understood economic relationship between land development and public transit access.

When transit again became a "favored" mode of transportation in the United States and federal funds became available to construct new lines, much of what the transit operator and real estate speculator of yesteryear had known had to be relearned at considerable expense. Yet the coordination of land development with public transit in the 1970s is much different from that in the 1910s. Much current transit construction is occurring in older, mostly fully developed communities, whereas most real estate speculation is still taking place primarily at the urban fringe, which is dominated by the automobile. The dramatic

Figure 3. Baltimore Gardens site plan.

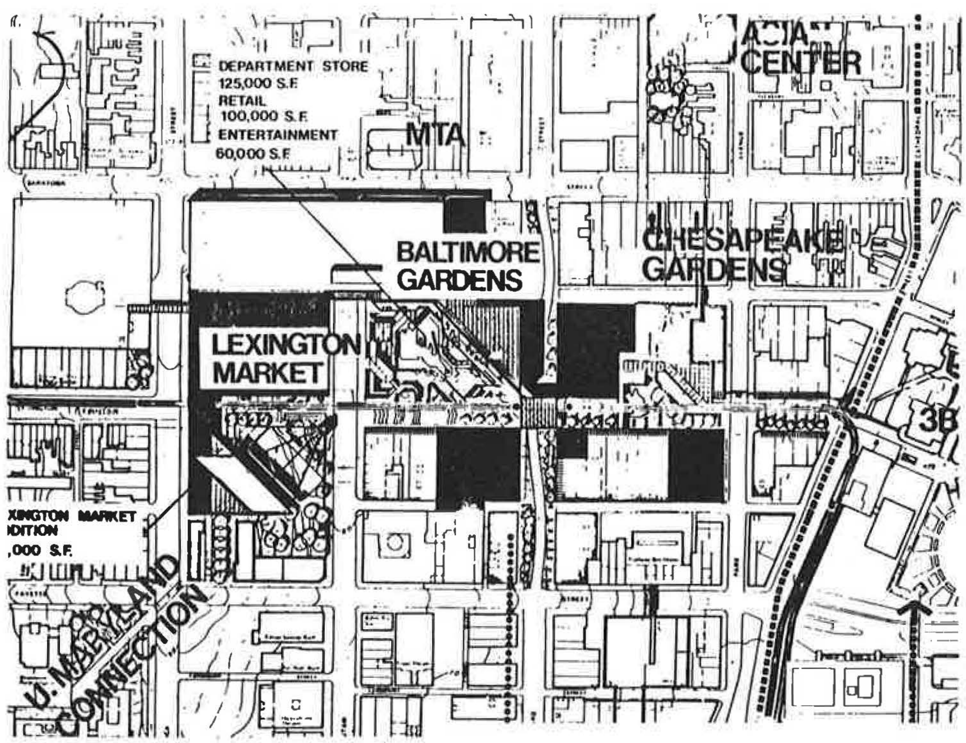


Figure 4. Baltimore Gardens: upper level at Eutaw Street.

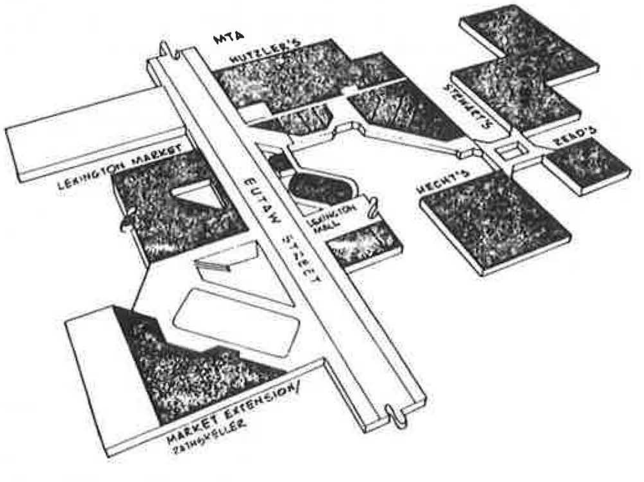


Figure 5. Baltimore Gardens: middle retail and entertainment level at Paca Street.

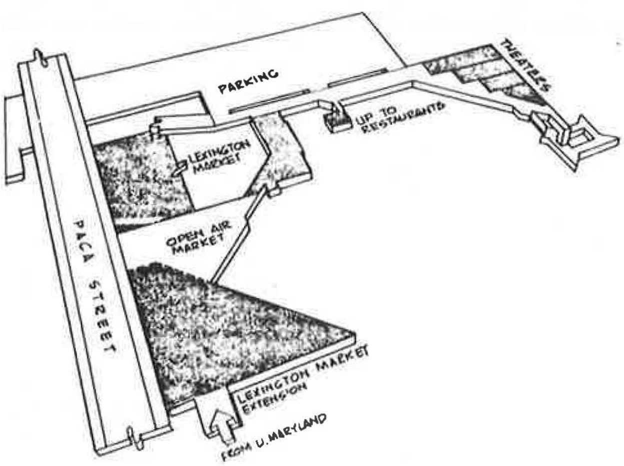
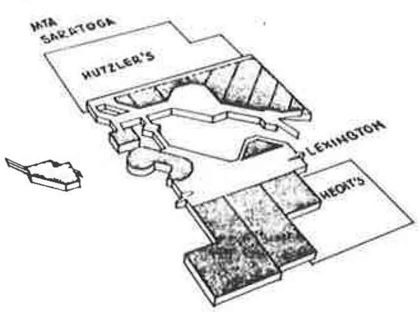


Figure 6. Baltimore Gardens: lower-level subway mezzanine at Lexington Mall.



increases in development along transit lines that occurred in past years are not likely to occur now, at least not if development is left entirely to the private sector.

The city of Baltimore went beyond the traditional passive municipal role of planning and entered the sphere of the private entrepreneur. The government became the planner and developer, a trend that has been growing steadily over the past two decades and has finally been relinked with transit planning and construction. To achieve this linkage, it was necessary to adopt innovative approaches.

Table 2. Funding request to UMTA for North Avenue station.

Item	Cost ($000s)
Land acquisition (30 000 ft^2 at $10/$ft^2$)	300
Business relocation	50
Demolition of existing structures	85
Site coverings, plaza development, coverings, and connections	400
Purchase of options or partial or full interests plus specialized planning and technical studies	65
Total	900

Table 3. Funding request to UMTA for Reisterstown Plaza Station.

Item	Cost ($000s)
Land acquisition ($4/$ft^2$)	
Private development (100 000 ft^2)	400
Public pedestrian connections (50 000 ft^2)	200
Subtotal	600
Demolition of existing structure	3
Site improvements and preparation; pedestrian path, underpass, and overpass	200
Purchase of options or partial or full interests in adjacent parcels plus specialized studies and appraisals	97
Subtotal	300
Total	900

Innovation, however, may involve--as it did in Baltimore--the development of a unique package of individual methods that in themselves are not new or especially innovative. In fact, it appears that success is most likely when proven development techniques--those with which the municipality has had previous successful experience--are used in the joint-development process.

The Baltimore case illustrates the use of "tried and tested" development techniques in the pioneering area of joint development. In Baltimore, joint development involved the use of urban renewal and quasi-public management corporations. The use of these two techniques in a pioneering area such as joint development came about because Baltimore operated through the HCD, which had a tradition of decision making. The city already had a strong and active urban renewal program, and the public was accustomed to the city's activity in this area. Therefore, in implementing joint development, the city declared land around the transit stations to be urban renewal areas, which fall under the jurisdiction of the HCD. The city had also supported two previous quasi-public management corporations and was therefore acquainted with this technique.

Baltimore had submitted its application for joint-development funds to UMTA in January 1977. It was not until October 19, 1979, more than 2.5 years later, that UMTA approval was given. The delay in approving Baltimore's application may be attributed to a variety of causes. However, it is clear that establishment of the UMTA Urban Initiatives Program in 1979 provided the impetus for releasing the funds. Although the joint-development legislation had existed since 1974, joint development was given low priority because of competing demands for Section 3 funds. It was not until President Carter made urban revitalization a matter of administration policy that joint-development funding became available. In addition, since no additional appropriations were released by Congress, Baltimore's application necessitated shifting funds from other discretionary projects. It is clear from the Baltimore experience that a well-defined federal policy toward joint-development funding is necessary.

In spite of the difficulty in obtaining federal funds for joint development, UMTA has clearly articulated the requirement that municipalities that seek funds for rail transit construction must commit themselves to a program of land use plans, zoning policies, and development incentives that will "support or reinforce the developmental impact and shaping influences of the rail transit system" (6). Station areas are to receive specific attention so that high-density private development in the station areas will be maximized. The plans for Baltimore's station area development outlined in this paper should serve as a model for other urban areas seeking funding for rail transit systems.

ACKNOWLEDGMENT

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Abridgment

Transit Centers: A Means of Improving Transit Services

ANNE TAYLOR-HARRIS AND THOMAS J. STONE

The role of transit centers in improving the overall effectiveness of an urban bus transit system is defined and assessed. Transit centers are defined as physical facilities that facilitate the movement of buses and, thus, of bus patrons. Transit centers are more than park-and-ride lots because they can be located in high-visibility locations, even in the downtown core, and thus can serve to increase the attractiveness of transit. They are major transfer points at which several types of routes can come together. Express and local routes, as well as pulse-scheduled circulators, can thus provide the bus user with many potential destinations and greatly reduce transfer time. Transit centers can be located in the central city, on freeways, or in suburban activity centers. Planning guidelines are developed to assist in the successful planning and implementation of transit centers. These guidelines address general locational considerations, bus berths, parking, accessibility, and potential joint-development opportunities. These planning guidelines are used to locate and conceptually design a potential transit center for the Salt Lake City area. It is concluded that the impact of current pioneer transit-center projects in the United States should be closely monitored.

Transit centers are physical facilities that help to coordinate the movement of buses and people and thereby facilitate the use of transit. Each can generally be categorized as either a central-area, an on-freeway, or an outlying transfer center. The purposes of a specific transit center are usually defined by its location. Central-area centers provide off-street downtown distribution for radial express-bus operations. On-freeway transit centers are built right into the right-of-way of the freeway and thus eliminate the need for express buses to leave the freeway and travel on local streets to a suitable location for loading or unloading passengers (1). Outlying transfer terminals help intercept motorists and buses in an outlying area, facilitate passenger transfer to other express and local lines, and also provide convenient access for transit patrons.

The Denver Regional Transportation District has applied for funding to build three outlying transit centers this year and another three next year. The San Diego Transit Corporation has included four on-freeway transit centers and one suburban transit center in its Five-Year-Plan Update (1979-1983). These transit agencies are two of the pioneers in the use of transit centers for bus transit alone. This paper discusses the expanded use of the third type of center--outlying transfer--in medium-density communities with a bus transit system. Basic planning and design guidelines are explained and applied in relation to a conceptual design for a transit center in the Salt Lake Valley.

FUNCTIONS OF AN OUTLYING TRANSIT CENTER

Until recently, transit facilities located outside of the downtown area have been used to collect commuters from residential areas and thus have functioned solely as park-and-ride lots. Although this is still a major function of a transit center in an outlying area, it is not the only one. Such a center can also serve as a main transfer point between bus routes and can offer possibilities for joint development. Because available funding is at a premium, joint-development possibilities become especially attractive and can increase the feasibility of the transit center.

As an interface between line-haul transit and local collection (either by bus or by automobile), the transit center makes it possible to reduce local transit services into the city center. Passenger travel time can be reduced through an expansion of express service and through wider station spacings on express transit routes. Thus, the operation of a transit center as a transfer point to a line-haul service allows greater productivity for transit personnel and equipment, simplifies routing, and increases line-haul operating speeds and efficiency (2).

Parking at outlying transit centers is essential because automobiles provide important secondary distribution, particularly in areas where the operation of a local bus service is not economical (3). The availability of parking also encourages bus patronage in areas where car travel to the city center is inhibited by congestion and where daily parking is very costly or unavailable. In these areas, both park-and-ride and kiss-and-ride lots are used, primarily in the peak periods.

A transit center can also serve as a major transfer point between local bus routes. It could function either as a local feeder to other local routes or as a "pulse point" for routes that have the same scheduled arrival time. Pulse or timed-transfer routes are routes that arrive at the transit center at approximately the same time, thus facilitating high transfer volumes among the routes. The use of the transit center as the pulse point minimizes the delay involved in transferring and emphasizes the center's role as a major transit node.

Locating the transit center within an existing regional activity center makes the center itself the destination of many trips and encourages the use of public transportation by creating a highly visible, conveniently accessible center of concentrated public transportation. If the trip attractor near the transit center is a municipal building, an office building, or a civic or cultural center, many possibilities exist for joint development. Parking facilities could be shared, and special routes that originate and terminate at the center could be established. This type of location would generate additional business for restaurants, newsstands, and stores included in the transit center. Pulse-point operation and a location near a major trip attractor will extend the service of the transit center beyond peak hours. In addition, it may become feasible to combine urban transit and intercity bus transportation at the transit center.

PLANNING GUIDELINES

The extent to which a transit center will be used is primarily determined by its location, which should reflect land costs and availability, bus and street patterns, traffic conditions, passenger interchange volumes, peaking characteristics, origins and modes, and use of the surrounding land. Terminals should be located where substantial changes in population density form logical breakpoints for express service to the city center. Parking becomes increasingly important as population density declines because the proportions of park-and-ride and kiss-and-ride passengers increase. This occurs as the distance from the city center increases (2). The decision to park and ride is largely determined by the trade-off between the inconvenience of and time lost in changing modes, the higher parking costs downtown, and the strain of driving in congested traffic. Thus, outlying parking facilities are most used wherever the multimodal trip to the city center is cheaper and faster than the trip by car. The bus service from the transit center to the central business district (CBD) must be fast and frequent. Transit fares and parking fees should be less than the cost of driving to and parking in the CBD.

To act as a local-express transit interchange, the transit center should be located where express transit and local lines intersect and/or where there is a natural convergence of bus routes on approaches to the transit station. This convergence is also essential for pulse-point service. The transfer point should be located at an outlying activity center that generates its own traffic. Location near a government or privately developed trip attractor will provide opportunities for joint development. Because all of these conditions may not be satisfied by any one location in the existing transit network, it is important to consider sites at which a transfer would simplify service scheduling and dependability over a direct bus routing, where local bus routes can be rerouted to serve express transit service, or where minor modifications in the existing route structure will make the network more effective or efficient through the use of the transit center.

There should be good highway access to the transit center. Access should be upstream from points of freeway convergence or interchange, where peak-hour congestion is typical. Ideally, the transit center should be located within a major bus corridor that connects it with the CBD.

Outlying bus parking sites should also have adequate land for existing and future needs. The site should be compatible with adjacent land uses, should not adversely affect nearby environments, and should achieve a reasonable level of use relative to development costs. Site selection should give priority to land currently used for parking, undeveloped or unused land now in public ownership, and undeveloped or developed private land (2).

DESIGN AND OPERATING FEATURES

The transfer from car to bus or from one bus to another breaks up a trip and involves penalties in travel time and convenience. Thus, the design and operation of the transit-center terminal should make transfers as quick and easy as possible. Passenger interchange should occur with minimal interruption to vehicle traffic and minimal deviation of buses from their normal routes. Internal site design should minimize pedestrian travel and give priority to interchanging passengers. Priority should be given to various functions of the transit center in the following order (2): (a) bus loading and unloading, (b) passenger-car unloading, (c) passenger-car loading (kiss-and-ride), (d) bicycle parking, (e) short-term parking, and (f) long-term parking.

At stations that have low traffic volumes, buses may share parking area roadways with kiss-and-ride and park-and-ride traffic. Kiss-and-ride drop-off areas should be close to the terminal entrance. A holding or short-term parking area for passenger pickup should also be provided. All parking and circulation areas should be clearly marked. Principal loading areas should be sheltered, and a covered walkway should be provided for any remaining distance to the bus boarding areas.

The size of the transit center depends on (a) the number of bus routes it serves and the headways on these routes, (b) the number of passengers served, (c) the proportion of park-and-ride and kiss-and-ride patrons, and (d) the extent of joint development associated with the facility (parking or ancillary).

The number of bus berths should be based on the maximum number of buses in the terminal at any given time. Berth requirements will depend on peak-hour passenger volumes and berth turnover. Bus layover time should be minimized during peak periods; 5-min dwell times are a desirable maximum. This allows a turnover of 10-20 buses/h/berth (2). Pulse-point scheduling increases the required number of berths and could reduce the turnover rate, since pulsed buses must dwell at the center to facilitate transfers.

Parking capacity should be scaled to roadway capacity as well as to parking demand and bus-service potential. If, for example, bus service is provided exclusively for park-and-ride or kiss-and-ride, space should be provided for 400 cars to justify 10-min bus service during the peak hour. This relationship assumes that typical peak-period loadings of 45 persons/bus will transport 270 passengers (200 automobile drivers and 70 kiss-and-ride passengers) and that 50-60 percent of the daily arrivals are in the peak hour. Studies of existing outlying transit parking facilities show an average daily turnover of 1.1 cars/space and about 1.2 transit trips generated per parked car. Kiss-and-ride passengers make up 20-40 percent of total peak-hour station arrivals (2). Most transit centers, however, do not cater solely to park-and-ride patrons. Because of the availability of transfers from local routes and the fact that patrons arrive and depart on foot, parking requirements will be decreased.

CONCEPTUAL DESIGN FOR SALT LAKE VALLEY TRANSIT CENTER

Salt Lake City is oriented north-south because of geographic barriers on the east and west sides. A site in Murray, a suburb about 8 miles south of the downtown core of Salt Lake City, was identified as a potential transit center. This site is located one block from the major north-south transportation corridor of the city. The area is a good breakpoint between the residential development to the south and the business and commercial areas that increase in density to the north. The site is in a redevelopment area, adjacent to a proposed new city hall and civic center.

In the existing route structure, a maximum of 15-17 buses/h could use the center. Since each berth has a capacity of 10-20 buses/h, this service frequency can be accommodated by one berth to serve each direction of traffic. Providing two berths for each direction of traffic will allow for a 100 percent expansion of services. Several existing bus routes converge near this area. Thus, although timed transfer routes are not used at this time, they could be established by making only minor modifications to the existing route structure. If pulse-point service were to be initiated, the berth requirements would have to be increased to accommodate the number of buses dwelling simultaneously at the transit center.

Since the transit-center site is adjacent to the proposed site for a city hall, there would be a good opportunity for joint development. Parking could be shared, bus routes serving the city hall could be set up to begin and terminate at the transit center, and fast-food stands, restaurants, newsstands, and shops would have many potential customers. A transit information center could also be provided. This joint development would encourage and facilitate the development of office space adjacent to the city hall, encourage transit use, and facilitate pedestrian and bicycle access to the city hall (4).

Two designs could be developed for the Salt Lake Valley transit center. Concept 1 would include a pedestrian island that has bus circulation on each side. The island could be covered by a canopy that extends the full length of the bus-loading bays and covers all but a portion of the waiting buses. This central pedestrian island could also provide transit information displays, newspaper racks, and other amenities for patrons (5). Concept 2 would provide pedestrian facilities on each side of the transit center. This design would be more costly, since shelters would have to be built on both sides of the street, but it would ease bus maneuvers and turning movements and reduce conflicts between buses and pedestrians.

Standard dimensions must be included in the design of the bus berths. The entire length of the berth must be a minimum of 65 ft, and a minimum of 22 ft of roadway width is required for the bus pull-out maneuver. The depth of the berth must be at least 8 ft (2).

If it is assumed that only half of the transit-center users during the peak hour will be park-and-ride patrons or city hall employees using the parking structure, the minimal number of required parking spaces at the center would be 200. Thus, the first phase of transit-center development would include four sawtooth bus bays (or more if pulse-point service is implemented) with covered shelters, 200 automobile parking spaces, bicycle parking, pedestrian crossings (which could be grade separated between the city hall and the parking lot) and ancillary facilities.

As use of the transit center becomes more popular, its services could be increased. Additional routes could be added where the demand is evident. The number of pulse routes could be increased as the number of common origins and destinations increases. Space is available for the expansion of parking facilities as the number of park-and-ride passengers increases. The facility and the adjacent roadway network will be capable of handling this potentially large increase in bus volumes (4). Since the design allows flexibility in service areas that may be expanded at the center, the transit center would continue to provide fast, dependable transit services to downtown, reduce vehicle miles of automobile travel, and reduce downtown parking space requirements in the Salt Lake Valley for many years to come.

SUMMARY

Outlying-transfer transit centers provide convenient access, collection, and transfer services at a single location within an existing community activity center. Many of the potential uses of a transit center can be developed through only minor modifications in the existing transit and highway networks. Through coordination with city governments, such as in the example given, a public transit agency could effectively reduce the vehicle miles of automobile travel in the region and encourage transit use through the establishment of transit centers. Federal funding support for such centers could be available from the Urban Mass Transportation Administration (UMTA) either under Section 3 (Discretionary Capital Projects Funding) or under the new Urban Initiatives Program. If accepted by UMTA, these projects would be funded on the basis of 80 percent federal and 20 percent local funding.

Since the many uses of outlying transit centers are still being investigated, any experimentation in U.S. cities should be publicized and recorded for use by other cities interested in establishing transit centers.

ACKNOWLEDGMENT

The research reported in this paper was completed while we were at the University of Utah.

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Abridgment

Security Considerations in the Design and Operation of Rapid Transit Stations

STEPHEN J. ANDRLE, BARRY BARKER, AND MARVIN GOLENBERG

Design principles for rapid transit stations and off-peak transit ridership as a function of personal security are discussed. A survey was conducted at two rapid transit stations in Cleveland, Ohio, for the purpose of determining user attitudes toward personal security and developing station design principles based on the findings. The major finding is that a "critical mass" of station patronage seems to be required before people feel secure in rapid transit stations. People avoid underused stations (which exacerbates the problem of poor patronage) and avoid riding in off-peak time periods at all stations. In both cases, survey respondents stated that they feel vulnerable in a transit station when there are few people around. Ironically, poor station patronage, which is considered to be a security problem, is largely a marketing problem, and improving off-peak ridership, which is generally considered a marketing problem, is largely a security problem. People provide the best security. It is concluded that, although traditional security measures such as good lighting, well marked stations, and security patrols are beneficial, improved security and improved transit marketing are closely associated and should be considered together in transit planning.

This paper discusses an issue that is of critical concern to mass transit riders--personal security. A poor reputation for security can undo the public goodwill engendered through efforts to improve public transit. This paper argues that security measures need to be considered in the design of new transit stations and in the refurbishing of existing stations. Neighborhood and microenvironment characteristics need to be considered early in the design process. The selection of major bus-rail transfer stations must also be considered to encourage a "critical mass" of people at each station.

This paper also argues that there is more to increasing off-peak ridership than improving service frequency or destination opportunities. There is considerable evidence that people actively avoid off-peak use of transit for security reasons even though transit would otherwise be convenient. It is necessary to change this before other improvement measures can have the desired effect. This paper suggests that an investment in improved transit security may be an essential first step for troubled systems before public transit can become a full-service travel mode for the average citizen.

The problem that prompted this study is the extremely low rate of use (approximately 250 boardings/day) of the East 120th Street rapid transit station in Cleveland. The view of the station from the street is blocked, because of its location in an industrial railroad right-of-way, and the station must be entered through a tunnel that has a blind turn and a steep stairway. The station also forms a boundary between two neighborhoods that are markedly different in ethnic composition. The combination of a physical design that prevents transit riders from being seen from the street and a location that suffers from neighborhood friction has earned the East 120th Street station the reputation of being unsafe.

By comparison, the University Circle station, located only one stop away, is heavily used. Although this station also suffers from tunnel access with blind turns, it is a major bus-rail transfer center and has denser adjoining land uses.

A platform survey was conducted at each of these two stations on Thursday and Friday, May 3 and 4, 1979, to determine user perceptions of personal security and to test user reactions to proposed security improvements. Although riders perceive the stations quite differently, there are key similarities in the way they perceive personal security. From the survey responses, a set of design principles and operational practices that make for safer rapid transit stations were developed. These principles are presented below and are followed by an analysis of the survey results.

DESIGN PRINCIPLES AND OPERATIONAL PRACTICES

Several design principles and practices that provide guidelines for improving the security of the Cleveland rapid transit system in general and the East 120th Street station in particular emerged from the traveler interviews conducted at the two Cleveland rapid transit stations:

1. A critical mass of people is required in a rapid transit station before people feel secure. The very fact that station use is low, for whatever reasons, will discourage additional users.
2. When a station is shared by two or more neighborhoods that have distinctly different ethnic composition, each neighborhood should have its own access to the station area. Although people will mix satisfactorily on the station platform, they are reluctant to cross neighborhood boundaries to enter a station.
3. People perceive certain stations as safe and others as unsafe depending on the time of day.

Table 1. Summary of selected survey results.

Question	Percentage of Respondents	
	East 120th Street Station	University Circle Station
Are the following station improvements important to improve security?[a]		
Presence of attendant at all times	81	73
TV surveillance	69	65
Security officer	80	89
Visibility from street	66	57
Relocation of station	23	NA
Would you feel safer at a relocated station?[b]		
Going to the station	43	13
In the station	42	17
On the platform	38	15
Do you feel safe now?[c]		
In your neighborhood	94	93
Getting to the station	85	91
Riding the bus	69	89
Riding the rapid transit system	91	91
In the station	61	77

[a]Responses indicate those who answered "very important" or "moderately important".
[b]Responses indicate those who answered "yes".
[c]Responses indicate those who answered "yes" and "mostly".

Stations that have low off-peak use and poor visibility from the street are most often perceived as dangerous.

4. Because of the safety differences between stations--both real and perceived--good lighting and station identification are important. People fear missing the correct stop because of difficulty in reading station signs at night.

5. Enclosed walkways are universally perceived as dangerous, especially if there are blind turns. This is true both day and night. Steep and deteriorating stairways in tunnels add the danger of accident to the risk of crime.

6. Certain bus routes are perceived as dangerous whereas others are considered safe. Identifying hazardous routes and improving security on these routes would tend to increase bus use and, potentially, transfers to the rail system.

7. Peak transit users dominate the ridership sample, partly because of the perceived dangers of riding during off-peak times. Improved security measures can be a tool for increasing off-peak ridership.

8. To be effective, new security measures must be made known to the public. Good public information is essential.

PERCEPTIONS OF PERSONAL SAFETY

Both male and female transit riders feel that the most dangerous portion of a rapid transit trip is entering the station and waiting for a train. An analysis of survey responses revealed that only 61 percent of the riders interviewed at the East 120th Street station felt safe all or most of the time when using the station whereas 95 percent felt safe in their own neighborhood and 85 percent felt safe while getting to the station. A summary of the responses is given in Table 1.

The rapid transit trains, on the other hand, are felt to be quite secure. At both stations surveyed, about 90 percent of the respondents felt safe on the trains all or most of the time. Buses, however, received mixed reviews. Only 76 percent of the respondents at East 120th Street felt secure on the bus all or most of the time compared with 89 percent at University Circle. Evidence indicates that there is a selective security problem on buses that depends largely on the neighborhoods through which a route operates.

There is also a time-of-day element in people's security perceptions that comes across clearly in talking with them but is not well reflected in the survey responses. When people say that they feel safe most of the time, that really means they feel safe at the times at which they currently travel. The hidden condition is that their travel times are carefully and consciously tailored to hours of peak activity. The adage that there is safety in numbers is particularly apt here. It is suggested, based on riders' comments, that the security problem at the East 120th Street station could largely be corrected by initiating marketing actions to improve the station's attractiveness to potential users in the neighborhood.

RIDER PERCEPTIONS OF ALTERNATIVE SECURITY IMPROVEMENTS

Manned Stations

The most favorably perceived actions to improve station security involve placing an attendant or security guard at the station full time. People were generally favorable to the idea of security guards assigned to each station, but they also recognized its limitations. It is clear that most criminal incidents happen very fast. If one guard has the platform plus several tunnel approaches to patrol, he or she is, at best, a deterrent only to the casual criminal. Several people expressed concern for the safety of the guard. Any isolated individual, even a security guard, is perceived as vulnerable in a rapid transit station.

Television Surveillance

Television surveillance was considered a reasonable action by 73 percent of the respondents at East 120th Street but by only 65 percent of University Circle respondents. The question that immediately arose was, Who is going to be watching the monitors and where will he or she be? If television surveillance is used, it must be coupled with very quick response. Monitoring at a central location will do little to improve people's sense of security. There was also great skepticism about how long the cameras would last; it was felt that they would quickly be vandalized or stolen.

Improved Visibility

Only 57-66 percent of the respondents felt that improved visibility from the street would improve platform security. Although the visibility issue is important (many respondents mentioned fear of the enclosed tunnels), there is also the feeling that people don't care, that the average person is not likely to respond to a cry for help or even to place a call for police assistance.

There are two sides to the visibility issue. On the one hand, future stations or station improvements should avoid enclosed tunnels with blind turns. This would improve the feeling of safety in the sense that a potentially dangerous individual could be spotted well in advance. On the other hand, people do not really expect help from passersby. Visibility is important, but improved visibility is probably not sufficient to turn around the negative perception of the East 120th Street station.

Station Relocation

Another measure under consideration for improving ridership at the East 120th Street station is moving the station along the line from its present location to the next cross street, Mayfield Road. A station entrance at this point would provide direct access to the center of the white neighborhood. The responses to this idea point up the importance of neighborhood identification with a transit station.

Only white females favored moving the station as a security measure. Black females, black males, and white males were strongly of the opinion that moving the station was unimportant or would have no security impact. What this seems to be saying is that moving the station would not have much of a security impact compared with manning the existing station with a qualified guard or attendant. On a comparative basis, however, whites generally favor the new location whereas blacks are split between perceiving no security benefit and perceiving lessened security.

The ethnic differences in relative perceptions of personal safety at the present East 120th Street station and a relocated station point up the importance of neighborhood boundaries in the location of rapid transit station entrances. The East 120th Street station is located at the boundary of two markedly different residential areas. Residents of one neighborhood are reluctant to pass through the other to reach the rapid transit station. The platform area, however, is viewed as neutral ground.

The conclusion to be drawn from this observation is that each neighborhood should ideally have its own access to the transit station. It must be perceived as "our station". When neighborhoods of a distinctly different makeup share a station, a good planning principle is to provide access to each neighborhood.

ALTERNATIVE ACTIONS TO IMPLEMENT DESIGN PRINCIPLES

Based on the design principles mentioned earlier and an analysis of the survey findings, there are a number of actions that could be taken to improve use of the East 120th Street station:

1. Some buses could be rerouted so that bus-rail transfers occur at East 120th Street instead of University Circle. Some buses are currently diverted to University Circle because there are no transfer facilities at East 120th Street. This would infuse new ridership into the East 120th Street station, which would help to reduce security problems.
2. An experimental neighborhood feeder bus program serving both local neighborhoods and part of University Circle could complement the present University Circle, Inc., demand-activated bus service and improve the market penetration of the East 120th Street station.
3. Construction of bus-transfer bays and a park-and-ride lot at East 120th Street would facilitate bus transfers and also provide an expanded market area for the station through improved automobile access. A number of riders currently park on the street at East 120th Street, which indicates a latent park-and-ride market.
4. Lighting and station signing should be improved. This should largely be accomplished through the programmed station improvement project that is soon to begin. Whenever it is reasonable, tunnel access should be replaced with open stairways.
5. The present entrance to the East 120th Street station should be closed. This entrance tunnel is universally perceived as dangerous because of the blind turns and steep stairs. In addition, its proximity to the overpass at Euclid Avenue is disadvantageous because walking under the overpass itself constitutes a security problem.
6. Two new entrances should be opened at the south end of the East 120th Street station platform, nearer Mayfield Road. One entrance should serve the Wade Park area and the other the Murray Hill area. Bus-transfer and park-and-ride facilities could potentially be developed on the east side of the rail right-of-way. Tunnels should be avoided in constructing the new entrances.
7. A restructuring of the fare-collection system should be considered so that the entire platform and the tunnel approaches are accessible only to those who have paid the fare.
8. A station security program should be considered, at least during off-peak periods, including midday and early morning. Depending on budget limitations, a full-time attendant would be beneficial.

ACKNOWLEDGMENT

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Discussion

Larry G. Richards

Andrle, Barker, and Golenberg have discussed a problem of critical importance for designers and operators of transit systems. Security, both actual and perceived, is a major factor in travel mode choice and patterns of transit use in large cities. The design and renovation of transit facilities to enhance both security and perceived security should be a central concern for operating agencies. This discussion has three purposes: (a) to highlight certain results reported by the authors and to emphasize some of their design recommendations, (b) to relate their findings to other research in this area, and (c) to provide references to the relevant literature on security planning and design.

PERCEIVED SECURITY

This paper demonstrates a concern about security among users of rapid transit at two stations in Cleveland. A perception of poor security is said to explain the low pasenger volume at the East 120th Street station. A platform survey of users at two stations yielded information on user evaluation of possible security improvements and their perceptions of the relative risk of various segments of a transit trip.

Previous research has demonstrated the importance of perceived security to travel mode choice and patterns of transit use, and a systematic study of a major transit system found that how security was perceived was the major factor that differentiated frequent users, infrequent users, and nonusers of transit (1).

RELATIVE RISK OF VARIOUS TRIP SEGMENTS

The authors' finding that more survey respondents at the East 120th Street station were satisfied with the safety of rail rapid transit than with the safety of the bus is the opposite of results obtained in Chicago. Ferrari and Trentacoste (2) reported that safety was one of the major reasons patrons in Chicago chose the bus over the elevated train for their trips. The el in Chicago was rated much less safe than the bus system.

In the Carnegie-Mellon University study of the Chicago transit system (3), respondents also rated their perceived security during various segments of a transit trip. Riding the bus was perceived as the safest activity, followed in rank order by waiting for the bus, walking to the rapid transit station, riding the train, waiting at the station, and entering and leaving the station.

Thus, the ordering of the safety of trip segments found by Andrle, Barker, and Golenberg generally agrees with that found in the Chicago study except for the relative safety of the bus versus the train for the East 120th Street respondents. The conclusion that the security of the bus is a function of the route traveled is probably correct. Thus, bus access routes to the East 120th Street station should be selected for their safe image.

USER PREFERENCES FOR SECURITY IMPROVEMENTS

The authors' results agree with those of several previous studies on user preferences for various security measures (1,3,4). People generally prefer security measures that involve manpower (e.g., security guards and attendants) to electronic surveillance, communications and alarm systems, or design features. However, passenger discomfort in the station environment is often related to design features (1), and various low-manpower countermeasures may effectively reduce station crime (5).

TERRITORIALITY AND DEFENSIBLE SPACE

The description of the East 120th Street station and the surrounding neighborhood situation is especially important. It relates this study directly to Newman's concept of defensible space (6), which includes the notion of territoriality discussed by the authors. The East 120th Street station violates all four of Newman's criteria for defensible space: (a) It lacks adequate territorial definition, (b) it is not subject to easy surveillance, (c) it does not interface with safe and/or busy public areas, and (d) it is isolated and set apart from community activity patterns. The suggestion that separate entrances from the two neighborhoods would facilitate use of the station is very important and should be more completely examined, both in this case and in others. A survey of nonusers is needed to determine how many people do not use the East 120th Street station because they are reluctant to cross territorial boundaries.

NEED FOR NONUSER SURVEY

Although this study does demonstrate that security is a concern among the users of the Cleveland transit system, it does not demonstrate that poor security is driving away users or is the reason that nonusers are avoiding the system. To show that, a survey of nonusers and former users would be necessary. If peak-hour users are concerned about their personal security, less frequent users and nonusers may be even more so.

CONCLUSIONS

Andrle, Barker, and Golenberg were interested in the redesign and renovation of a particular transit station. Their recommendations are generally sound and conform to design principles suggested elsewhere (7,8). The survey results replicate previous findings, except for the relative safety of the bus as perceived by respondents at the East 120th Street station. The actions suggested to implement the design principles are all good, and the authors' conclusions are well taken. It is hoped that there will be a follow-up report to indicate how these changes have in fact influenced perceived security and station use.

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Reliability of Fare-Collection Systems for Rail Transit: An Overview

LOUIS D. RUBENSTEIN

The present performance of graduated-fare automatic collection equipment is compared with that of similar fare-collection systems, desirable performance is estimated, and research and development needs are identified. A series of flowcharts for three actual rail systems that indicated the range of functions and approaches that could be incorporated into a fare-collection system were developed. Queuing models could not be used directly to estimate the impact of the collection system on passenger flow without developing a two-stage model by use of the binomial probability distribution. Reliability data were collected by using interviews and the review of operating records. The data-collection methods varied greatly. Mean transactions between failures was found to be a useful and practical measure for comparing equipment reliability. The operating costs of rail transit fare-collection systems vary between 7 and 31 percent of revenues collected. The reliability of fare-collection equipment varies between 40 000 transactions/failure for a token-accepting turnstile to several hundred transactions per failure for a stored-value farecard vendor. Improved performance is obtainable, but the potential extent is unclear. Systems with a combined reliability of 0.22 percent failures/passenger can function without station attendants. It is important to specify failures in terms of component replacement and in terms of clearing of jammed tickets or money. The results provide an initial basis for comparing the performance of alternate fare-collection systems and focusing development resources.

This paper discusses various rail transit fare-collection systems (ranging from the simple to the complex), the performance of automatic-fare-collection (AFC) systems, methods of procurement, analysis of impacts on passenger flows, and longer-term fare-collection development needs for the industry. Interest in the reliability of AFC systems has increased as a result of the experiences of several new rail transit systems. This paper reviews this and related issues and reports on some of the systems analysis work conducted by the Jet Propulsion Laboratory for the Subsystem Technology Application to Rail Systems (STARS) program of the Urban Mass Transportation Administration (UMTA).

DESCRIPTIONS OF TYPICAL SYSTEMS

Fare-Collection Market

Almost $3 billion in passenger fares are collected annually in the United States. The largest proportion is for bus transit. Since the bus driver is available to supervise the operation of the fare box, most bus-fare functions can be completed with a minimum of complexity. Commuter rail collects almost $400 million annually in passenger revenue. In urban rail transit, which collects $700 million annually in revenue, high passenger volumes in limited space and time have necessitated the use of passenger-fare-processing machinery (1, p. 15).

System Elements

Urban transit fare-collection systems contain two essential elements: a method of collecting the revenue from the passenger and a method of controlling access to the station or the train. There are other elements, but some form of these two will be found in any system. At a more detailed level, additional elements can be identified. These include form of payment, fare structure, ticket type, ticket vending, change making, entry-exit gates, money processing, compliance enforcement, equipment maintenance, station attendant, passenger assistance, and management information.

Many of the definitions of system elements will be obvious from a discussion of these elements later in this paper. However, there are so many variations to fare structure that it is worthwhile to define this element more precisely. This is done in Table 1, which is adapted from a recently completed survey of fare-collection equipment (2, p. 5).

The term automatic fare collection relates to the extent of manual effort required to interface with passengers and operate a system that implements a particular fare structure. Common usage usually associates AFC with a variable-fare structure, although it could also apply to a fixed-fare system, depending on the specific equipment used.

For many of these elements, there may be as many as 10 different methods of performing a function. The number of potential combinations, and thus of different fare-collection systems, is enormous. A good understanding of the interaction of these elements can be readily obtained by examining several different systems now in use.

System Flow Charts

Three systems that illustrate a variety of fare-collection techniques were selected and are shown in Figures 1-3. These charts describe several of the essential differences between the systems; they are not a complete description. The systems are examined here in order of ascending complexity.

New York City Transit Authority

The form of fare payment on the New York City Transit Authority (NYCTA) is cash, paid to the station agent in exchange for a token. The fare structure is flat--that is, the same between any two stations of the system. This can lead to great inequities in charges per mile for different passengers. Nevertheless, most urban transit systems operating within one political subdivision (with distances of less than 1.1 miles between stations) have selected a flat-fare structure (3).

A token is used as a ticket to gain entry. These tokens are manufactured especially for the NYCTA, which sends inspectors into the contractor's plant to prevent unauthorized production. The token is used thousands of times in its life, and the cost per use is negligible.

As the flow chart in Figure 1 indicates, 50 percent of the passengers will already have a token and proceed directly to the gates. One-third of the passengers will purchase from one to several tokens from the station agent, who performs the ticket-vending and change-making functions. More than 8 percent of weekly riders will request a return coupon valid for a free ride by senior citizens, the handicapped, and, on weekends, all passengers.

The prime entry-exit gate is a mechanical turnstile that accepts the token. The turnstile turns are recorded on a meter enclosed in a sealed welded steel box. The station agent collects tokens from the turnstile several times a day and sells them to the public. The agent is financially responsible for any failure of the token sales and cash collected to balance against turnstile registrations. The revenue section collects funds from the station agent. As the agent counts tokens, he or she visually inspects them for counterfeits (slugs).

More than 15 percent of NYCTA passengers enter without using a token. These include the return portion of senior citizen and weekend half-fare trips plus students who have passes purchased through their schools. These passengers enter through a slam gate supervised by the agent.

The equipment is reliable and rarely needs maintenance. In addition to providing information, the presence of a station attendant gives an added sense of security to passengers. Even if all station-agent functions were replaced by reliable equipment, management might still decide to keep agents in the station.

Port Authority Transit Corporation

The Port Authority Transit Corporation (PATCO) uses a zone-fare structure (see Figure 2). The system length is 22.5 route-km (14 route miles), broken into five zones; fares range between $0.55 and $1.15 and average $0.12/zone. A thin [0.025-mm (0.0011-in)], magnetically encoded, stored-ride plastic ticket is used. Tickets cost $0.12 new but are used hundreds of times. The cost of reencoding and reissuing a used ticket is $0.01. Printing over the plastic is not done.

Forty percent of riders purchase their tickets in the form of 10-ride tickets from newsstands. Newsstands in the PATCO stations are required to sell tickets and are allowed 30 days to pay for them. This cash float is a strong incentive. Single-ride and two-ride tickets are sold through cigarette-type vending machines, in which they are stored in separate stacks according to the particular zone-to-zone combination.

Thirty-five percent of PATCO passengers use separate change makers before using the vending machines. The change makers are rented from and maintained by the manufacturer.

The entry gate has a card transport that moves the ticket through the machine. When the ticket is inserted, its validity is checked for proper entry zone, and a code is written that indicates that the next transaction must be an exit transaction. One ride is also deducted. At the exit station, the gate checks the ticket for the proper zone. A ticket with remaining rides will be returned to the passenger; otherwise, it will be captured. Used tickets are collected, sorted, reencoded, and resold.

Money processing is greatly simplified because of the bulk sales to newspaper stands. The revenue department staff collects funds from the vendors and change makers and restocks them.

Compliance is aided by closed-circuit television and police patrols. Equipment maintenance and jam rates are low enough to allow unattended stations. Before each rush hour, roving supervisors check each machine to ensure that it is working properly. In the busier stations, a supervisor is assigned throughout the rush hour.

At other times, a patron may use the phone for assistance. If his or her ticket is not valid at that station, the additional fare is deposited

Table 1. Fare structures in order of increasing complexity.

Type of Fare	Description
Predetermined	
Fixed (single rate)	No extra charge for transfers, same rate for all passengers on all routes between any two points
Flat (multirate)	One basic rate, may or may not charge for transfers, reduced rate for certain passenger categories, reduced rate for off-peak hours, Sundays, and holidays
Variable (computed)	
By zone	Fare rates in increments according to number of zones traversed by passenger, can provide fare classes as a function of day and passenger category
By distance (graduated)	Fare determined for each journey by distance traveled, reduced-fare classes can be provided by passenger category and time period

Figure 1. New York City Transit Authority flowchart: manned flat fare.

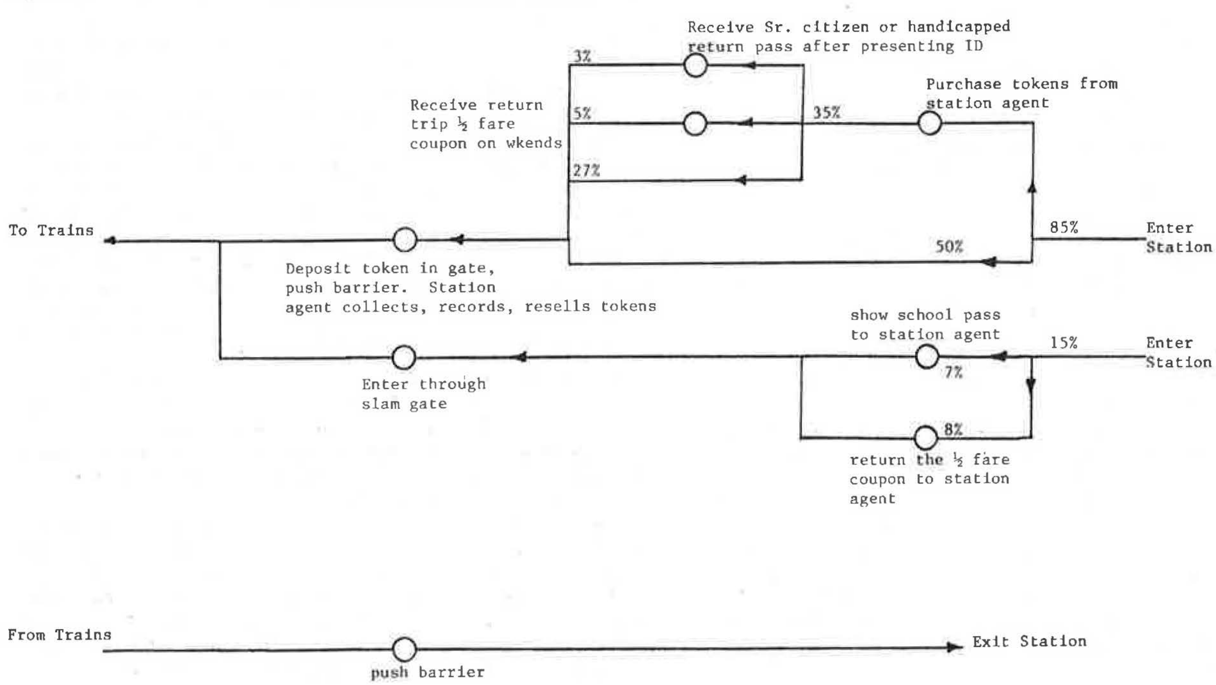
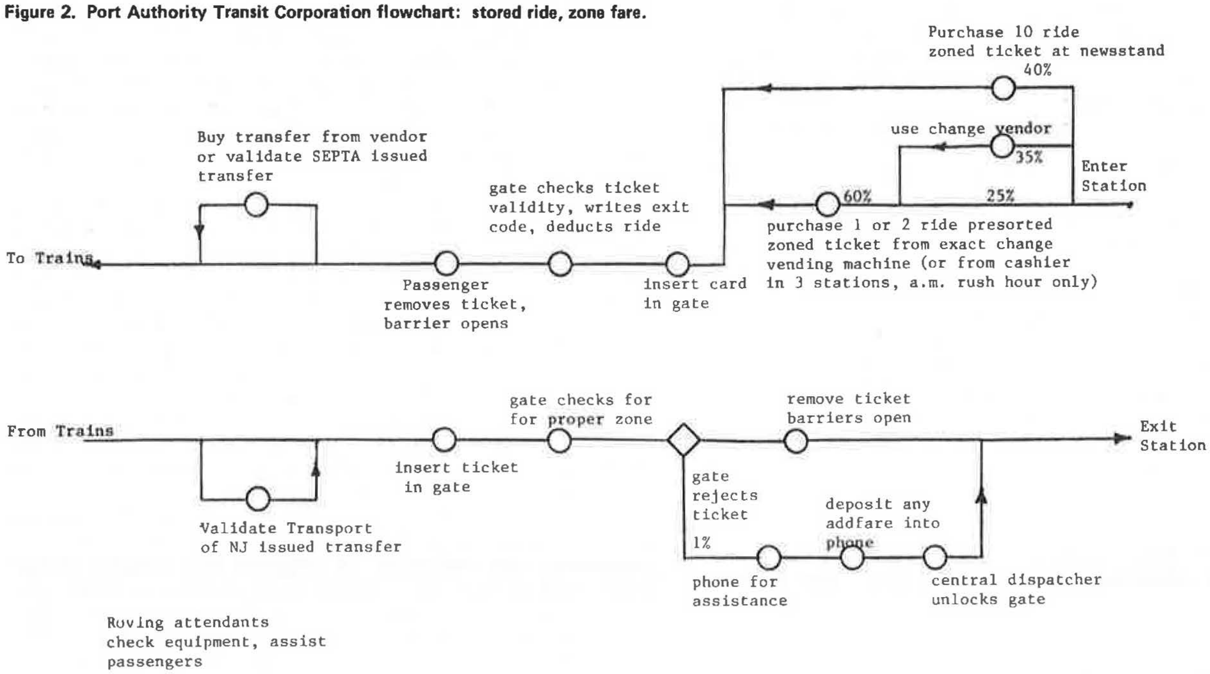


Figure 2. Port Authority Transit Corporation flowchart: stored ride, zone fare.



directly into the phone and a gate is unlocked by the observer of the television monitor.

Washington Metropolitan Area Transit Authority

The last and most complex of the three illustrative fare-collection systems is that of the Washington Metropolitan Area Transit Authority (WMATA). The Metro system is similar to the Bay Area Rapid Transit (BART) System in that it serves several political entities and is a combination commuter railroad and urban transit system. These conditions encouraged the adoption of a distance-related fare structure, which charges longer trips more than shorter ones and facilitates the accounting of subsidies from the various local governments that support the system.

It is also a stored-value instead of a stored-ride system--a marketing incentive. It has been stated that, if commuters have a valid subway pass in their pockets, they are more likely to use the subway for occasional short, noncommuting trips than if they had to pay a separate entry fee.

The fare structure is very precise. It charges 40 cents for entry, which allows 5 free km (3 miles) of travel. A fee proportional to the average of the air-line and route distance (11-12 cents/km) is charged for additional travel on each trip. The charge is rounded off to the nearest 5 cents. The system also accommodates special discount-fare programs for students, the elderly, and the handicapped, as well as midday discounts.

A very thin, magnetically encoded paper fare card is used to gain entry. The cost of each card is about 1 cent. The remaining value of the card can be printed onto it over its protective coating. The card is usually used fewer than 10 times before it begins to wear. Because the coding system is not particularly complex, it is possible that a limited number of persons have broken the code and regularly upgrade low-value farecards to an unauthorized higher value. In addition, it is possible for vendors to erroneously issue overvalued cards. It is very difficult to detect and locate any pattern of fare evasion, since there is no physical evidence. One detection method is to have the exit gate capture all cards and reissue new ones. The captured cards would be examined for fraudulent ones.

Fare-collection fraud can be attributable to either passengers or staff. All systems experience some fraud, but published data are not readily available. A key principle of fraud control is that its cost should be less than the amount of money saved. European experience with self-canceling surface transport fare-collection systems indicates that most systems lose between 0.5 and 5 percent of their revenue because of fraud (4). The systemwide imbalance between the value extracted from AFC tickets and the value of tickets sold at vendors is a measure of fare evasion in graduated-fare systems. Fare evasion for graduated- and flat-fare systems in the United States is in the same 0.5-5 percent range.

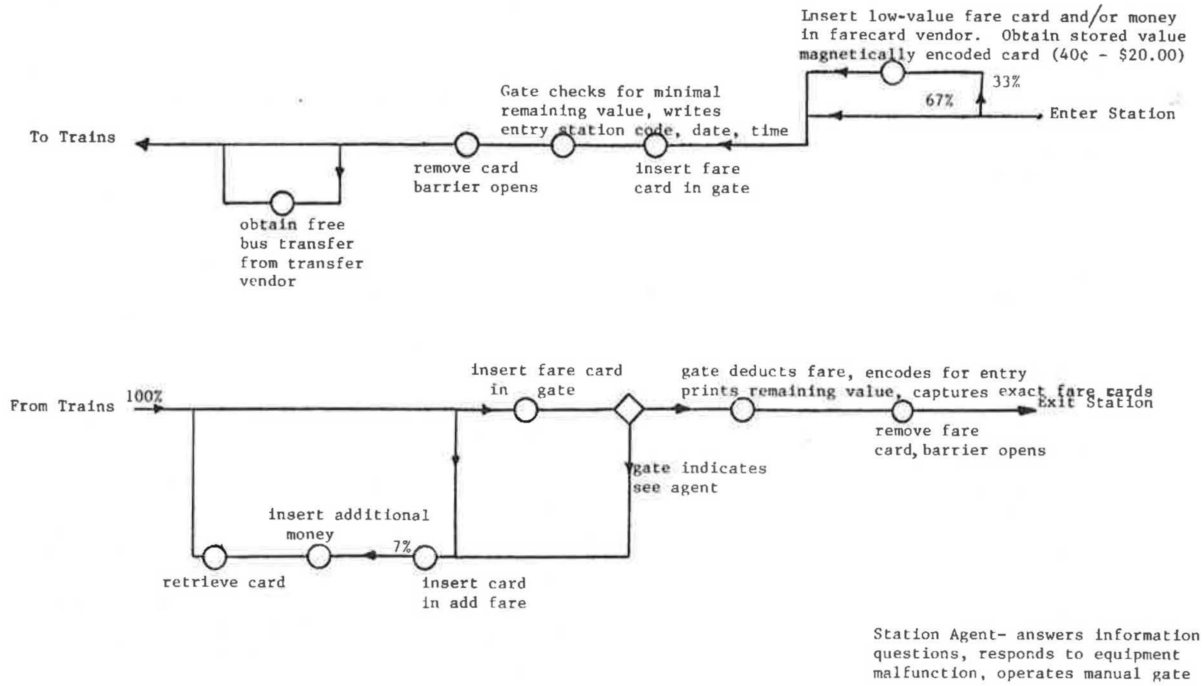
Farecards are sold by a versatile vending machine that accepts $1 and $5 bills, change, and low-valued farecards; issues a new farecard with any value between $0.40 and $20; and returns change.

The form of payment is cash, which has led to unexpected problems. Dollar bills, which cost about 1 cent to produce, are designed to be kept in circulation for 9 months, but it has been estimated that they currently remain in circulation for 18 months. Coins can usually last 17 years. The lowered physical quality of money leads to more jams in vendor and "addfare" machines. A common problem is bent dimes that have been used by passengers as emergency screwdrivers.

Thirty-three percent of persons entering a station will use the farecard vendor, and 67 percent will proceed directly to the gates (see Figure 3). A September 1978 WMATA survey indicates that approximately one-third of farecard vendor users are trading in lower-value cards.

The farecard is inserted in the gate and checked for minimal remaining value, and an entry and location code is magnetically written on the ticket. The card moves through the gate via the transport to the exit slot, where it is removed by the passenger. Card movement is intended to pace the movement of passengers through the gate.

Figure 3. Washington Metropolitan Area Transit Authority flowchart: stored value, distance-related fare.



While in the control zone of the station, a passenger may obtain a free rail-to-bus transfer from a separate transfer dispenser. A need for a machine-issued and readable bus-to-rail transfer has been expressed.

In exiting a station, the passenger inserts the farecard in the exit gate, where the travel distance is calculated and the proper fee deducted from the stored value. The remaining value is printed on the card. If the value is not sufficient, the card is rejected and a message to see the agent is displayed. The patron must then go to the agent, who will direct him or her to the addfare machine, a simplified vendor that upgrades the ticket upon insertion of the proper fee. The upgraded farecard is then used in the exit gate.

Money is collected from the vault chambers in the farecard vendors and addfare machines by revenue service and collection department staff. The station attendant does not have access to the vaults or perform any functions that involve the handling of money. This increases the attendant's security.

Compliance is enforced by closed-circuit television, the station agent, and the police.

The required equipment maintenance on the Washington, D.C., system has been much greater than desired. Clearance of jams and calling for maintenance repair are so frequent that the concept of reduced-level station manning is practically eliminated. Rapid response to maintenance calls by a large, widely distributed maintenance staff can lead to a high rate of equipment availability, in spite of frequent malfunctions, but at great expense.

Passenger assistance is provided by the station attendant.

The data acquisition and display system (DADS) monitors equipment performance and activity. This system also provides a sealed written record of each machine's transactions and receipts and generates a clock code that is used by the entry and exit gates to determine fares based on time of entry and to reject farecards where the time between entry and exit is greater than a prescribed value.

Cumulative statistics on fares extracted at gates, passenger flows, and vending-machine sales and receipts can be centrally polled at each mezzanine kiosk.

Reliability of System Elements

The reliability of the overall fare-collection system is determined by its individual components. Table 2 gives the mean number of transactions per maintenance action for several types of fare-collection equipment. It indicates vast differences in reliability and shows a trend toward decreasing reliability with increasing equipment complexity. It can be used as a guide in estimating achievable levels of improvement for present AFC equipment.

There are several definitions of reliability that can be used to relate equipment performance to activity. Performance can be described in terms of the capability to (a) complete all functions, (b) complete the more critical functions, (c) be repaired by level 1 (fingertip) maintenance, and (d) be repaired by level 2 maintenance (the replacement or adjustment of components). The mean number of transactions per maintenance action was selected as the definition that best corresponds to the ability of a fare-collection system to process large numbers of passengers with minimal expense and delay. It is also broad enough to apply to the various practices in use on different systems. (Maintenance actions include repair orders completed by maintenance staff, jams cleared by station attendants, and repairs completed by patrolling maintenance staff. The ratio of jams to hard failures usually varies between 3:1 and 5:1.)

The data were collected from different transit systems under varying conditions. In some cases, excellent records were available on maintenance actions and transaction rates. In other cases, an example of the best estimate available, without a special survey, was that one-third of the machines were serviced each day by roving teams of maintenance personnel in addition to logged calls.

The definition of failure also varies according

Table 2. Typical reliability of fare-collection equipment.

System	Type	Mean Transactions per Maintenance Action
NYCTA	Flat fare, token-accepting turnstile	40 000
CTA	Flat fare; coin-accepting, transfer-issuing turnstile gate	
	Type 1	800
	Type 2	2500
PATH	Flat fare, coin-accepting turnstile	11 000
	Flat fare, pass card, reader-conductive ink	≥50 000
PATCO	Entry-exit gate, magnetic card, stored ride, zone fare	6000
	Ticket vendor, sorted tickets	900
	Change maker	≥2000
BART	Graduated fare, magnetic-card-reading entry-exit gate that computes and prints remaining value	
	Type 3	4200
	Type 4	1200
	Farecard vendors	
	Type 3	1100
	Type 4	400
	Addfare type 3	1100
WMATA	Graduated fare, magnetic-card-reading gate	
	Entry gate	2000
	Exit gate (computes and prints)	500
	Farecard vendors	100
	Addfare	75
European surface transport	Cancelling machines	20 000
	Ticket-issuing machines	5000-10 000

Notes: CTA = Chicago Transit Authority; PATH = Port Authority Trans-Hudson.
Types refer to different manufacturers of similar equipment. WMATA data are for rush hours only.

to the system. On the NYCTA system, the station attendant performs no repair functions, and any equipment jam will result in a maintenance report. The BART station attendant will apply fingertip maintenance to clear farecard and money jams. These failures will never be reported, whereas a hard failure that requires a maintenance technician will be.

The NYCTA turnstile is simple, inexpensive, and extremely reliable (40 000 transactions/failure). The acceptance mechanism tests only the size of the token. It is estimated that 90 percent of the failures are actually jams caused by the insertion of foreign objects into the token slot. Records indicate that the jam rate will increase by 25 percent in the year after a fare increase. There is a 100 percent correlation between turnstile registrations and turns.

The CTA turnstile accepts coins and issues transfers. Some passengers will overpay for convenience, and the money received will not correspond to the barrier turns. Coins are collected in the type 2 machine in a sealed steel cylinder that is removed from the machine by the Revenue Department. The reported rate of transactions per failure for those machines appears to be unusually poor considering their lack of complexity. These data deserve closer investigation.

The PATH system uses turnstiles that are similar to CTA's except that they do not issue transfers. Their failure rate is 11 000 transactions/failure. Most of the failures are attributed to jams resulting from bent dimes. PATH has wired to several of its machines an independent change maker that accepts dollar bills, returns change after subtracting the fare, and releases the barrier lock.

A key observation is that the PATH system is capable of operating without station attendants and with equipment that has a rate of 11 000 transactions/failure. The system operates with a failure rate of 1 failure/11 000 passengers for turnstiles plus 1 failure/2000 passengers for the change makers. Assuming that one-quarter of the passengers use the change maker, the combined system failure rate is 1/11 000 + 1/4 (1/2000) = 2.2×10^{-4} failures/passenger. In other words, 0.22 percent of the passengers encounter a machine failure.

A similar performance criterion stated in previous studies should be noted (5, p. 47): "Observations made on other transit systems have indicated that any passenger confusion arising from the man-machine interface, which affects as many as 0.5 percent of the patrons, could easily be cause for general dissatisfaction." This would imply that, even if a machine were to "self clear" jams without the aid of a station attendant, at least 99.5 percent of passengers should be processed by the equipment without resort to manual assistance.

A year-long demonstration of nine Almex (Incentive AB of Sweden) multiride ticket cancelers was recently completed. This device is similar in appearance to a miniature time clock. The passenger inserts a multiride ticket into a slot, one ride is deducted by an internal paper cutter, and the passenger withdraws the ticket. The canceler makes contact with several electrically conductive stripes on the back of the ticket that form a binary on-off code.

PATH has placed the Almex cancelers on small stands in front of and wired to turnstiles. The gate can handle passengers who pay with cash or with tickets. The mean number of transactions per maintenance action was more than 50 000. Two passengers out of 1000 (0.2 percent) reported that they inserted their 10-ride ticket into the machine backwards and that, although the ticket was destroyed, the machine did not jam. Their crumpled ticket was exchanged for a new one by PATH.

The system was removed after the one-year test because of the cost of distributing tickets (commissions to retailers) and the lack of an urgent need for the added passenger convenience.

PATCO uses a zone-fare system with magnetically encoded plastic cards that are inserted into a card transport in the gate. No printing is done on the card, and few jams are caused by card wear. The mean rate of 6000 transactions/failure is twice that of BART or WMATA. The ticket vendor uses presorted stacks of different types of tickets. The rate of 900 transactions/failure is not as high as expected for such a simple machine.

The change makers used are separate units maintained and owned by the manufacturers and rented to PATCO. Their reported failure rate of 2000 transactions/failure appears to be better than when equipment with the same functions is incorporated as part of a larger, more complex machine.

The performance of BART and WMATA equipment is given in Table 2 for ease of comparison. No survey information was available from BART for the ratio of soft to hard failures. The ratio derived for WMATA was applied to BART and may lead to slightly pessimistic results.

The BART and WMATA equipment represents three different generations of the same basic design, two at BART and one at WMATA. Normally, each generation of equipment under development would be expected to be many times more reliable than its predecessor. Such is not the case here. This may indicate a problem in the transferral of information or the procurement process. It also leads to a continued expectation that the performance of the basic design can be further improved.

Information concerning European surface transit was developed in a survey conducted by the International Union of Public Transport and reported in 1973 (4). The figure given in Table 2 excludes servicing that results from false alarms and vandalism. Equipment developed since 1973 or used in a station environment rather than on a bus or at a stop might perform better than indicated. The ticket-issuing machines described accept coins only, no bills.

Fare-Collection Operating Costs

Both the capital and operating costs of fare-collection systems vary tremendously. A gate can cost from \$2000 to \$30 000 depending on its complexity and its function. Additional costs are incurred in the structural design of stations, especially at mezzanines because of the space required for fare-collection equipment.

Operating costs of several fare-collection systems, derived from a survey conducted in 1977, are given in Table 3 (6). Because WMATA ridership and receipts have more than doubled since that time, the figures should be used cautiously. A more up-to-date survey of this information should be conducted.

Although it is not otherwise described in this paper, mention should be made of the honor system used in Hamburg. Passes are sold through banks, vending machines, and retail outlets. There is no entry or exit control, but inspectors ride the trains and check for valid passes. The operating cost of the system is 7 percent of the revenue collected, or 1.4 cents/ride.

In spite of its successful application in several European cities, the honor, or self-canceling, type of system probably has useful but less limited application in the United States. The demographics of American cities are different from those of Europe, where the wealthier and not the poorer people tend to live in cities (there are some signs that this may be changing). The level of criminal activity is often less, too. In many European cities, the police are not even armed.

UMTA is investigating the feasibility of a self-canceling fare-collection system for bus transit in the United States. If it proves successful and compliance and enforcement problems do not develop, this system, applied to rail transit, offers the potential for large reductions in the cost of fare collection.

SYSTEMS EVALUATION MODEL

Two-Stage Model

A model has been developed to relate the performance of individual pieces of equipment to transit-station characteristics. The model consists of two stages. At the first stage, the average availability of a certain type of machine (e.g., ticket vendors) is used to calculate the probability that a given number of similar machines in a bank of machines in parallel operation will be available for use. The second stage of the model is a queuing model for multiple servers, which yields probabilities of waiting time, average queue length, average time in the system, etc.

Use of a two-stage model greatly simplifies analytic description and also relates two of the major processes that occur during station operations. These are the out-of-service condition of one or several AFC machines and the subsequent increase in arrival rates and queues at the operating equipment. An effort was made to develop a one-stage, closed-form, analytic model, but this approach was discontinued.

Equipment Availability Model

The probability p that a given machine is available for service at any instance in time is called availability and is defined as

$$\text{Availability} = \text{MTBF}/(\text{MTBF} + \text{MTTR}) \qquad (1)$$

where MTBF is the mean time between failures and MTTR is the mean time to repair the equipment. By use of the appropriate service rate, availability can also be expressed in terms of mean transactions between failures.

Availability, therefore, takes into account the maintenance of the machine. Thus, if a failed machine is quickly put back into service through improved maintenance procedures or assignments, a higher availability results.

The probability that a specific number of machines in a bank of machines will be available for use at a given moment can be calculated by using the binomial distribution. Thus, if p is the probability that a machine is available for use (its availability), the probability that x machines out of a bank of n machines will be available is

Table 3. Estimated annual fare-collection operating costs for six systems: FY 1978.

Item	NYCTA	BART	Hamburg	PATCO	PATH	WMATA
Cost (\$000 000s)						
Station personnel	80.8					
Stationary		3.8	0.3	0	0	1.6
Mobile		0.9	0.3	0.15	0.60	0.2
Equipment maintenance	3.5					
Field		0.6	0.03	0.16	0.16	0.8
Central		0.2	0.08	-	0.02	-
Collection	3.1	0.4	0.3	0.12	0.03	0.4
Revenue counting	2.2	0.3	0.04	0.03	-	0.3
Revenue accounting	0.3	0.1	0.2	0.01	0.22	0.06
Compliance enforcement	0.3	-	1.0	0.4[a]	-	0.02
Other	1.7	0.4	0.3	0.08	0.05	0.8
Total	91.9	6.7	2.6	0.95	1.1	4.2
Percentage of passenger revenue	19	31	7	7[b]	8.7	21

[a]With police.
[b]Without police.

$$[n!/x!(n-x)!]\,p^x\,(1-p)^{n-x} \tag{2}$$

Table 4 gives an example of probabilities for stations with nine fare gates where the individual gate availabilities (A) are either 0.85, 0.90, 0.95, or 0.975. These values are representative of field experience. For A = 0.95, the probability that eight of the nine gates are operable is 0.29; the probability that seven or fewer are operable is 0.057 + 0.006 + ... = 0.063. If the number of fare gates installed is based on 100 percent availability, this simple analysis indicates that, at least 6 percent of the time, at least two of the nine gates will be inoperable and large queues may develop.

The availability of the individual machine depends on equipment reliability (transactions per failure), passenger arrival rates, and the time required for a station attendent or maintenance technician to arrive at the scene and repair the equipment. Transactions per failure may also depend on the service rate. Several experts contend that, when AFC equipment is used at very high service rates, the solenoids heat up and the equipment does not perform as well. Reference to reliability criteria (7) indicates that even for non-military-specification-quality relays, one type of component in fare-collection equipment, a cycling rate lower than 1000 cycles/h will not cause a decrease in the individual part transactions per failure. However, a temperature increase from 25° to 47°C (77°-117°F) will cause a 20 percent increase in the failure rate. Conclusive data on this issue were not available for this paper, and the model used assumes a constant failure rate per rush-hour transaction.

Examination of even this model for the hypothetical case indicates the importance of high reliability levels. The number of simultaneous equipment failures increases at a much faster rate than the decline of equipment availability.

Queuing Model

Knowing the number of joint machine failures is a first approximation of the performance of the total system. It is possible to have conditions that lead to many public complaints even if several or all of the machines are working. A queuing model can develop more detailed information about these conditions.

The number of machines, their incidence of failure, the time it takes for them to be repaired, and passenger processing and arrival rates are all factors that affect queue length.

A standard multiple-server queuing model was used for illustration (8, p. 302). Such a model can be combined with the results of the equipment-availability model to indicate expected queue lengths and waiting times for varying numbers of machines in working order.

Table 5 illustrates the application of the model for a station with nine fare gates. Representative arrival and service rates were selected. The arrival rate was determined by assuming that 260 persons alight from a train and must be cleared within 2 min--that is, before the arrival of the next train.

The queuing model indicates that very long queues can be expected when fewer than six gates are operational. Based on the binomial distribution, this situation occurs with the existing equipment 4 percent of the time (A = 0.90).

With six gates in working order, there are at least 32 customers standing in queues. The mean time spent in the queue is about 15 s. The model also shows that the probability of a customer waiting for at least 30 s is 15 percent. The combined probability of a passenger waiting 30 s is the probability of six gates being in working order multiplied by the probability under this condition of a 30-s queue, or (0.04) (0.15) = 0.006.

These models show the type of operation that can be expected with varying levels of availability and therefore establish a planning tool for assessing the magnitude of the effect of a change in machine availability. Studies of this kind can be tailored to individual stations and various availability levels.

FARE-COLLECTION DEVELOPMENT NEEDS

Several fare-collection problems apply to all transit systems, whereas others apply to only a few. Problems with coin acceptors and bill validators--i.e., frequent jamming, wear, and acceptance of foreign coins and slugs--affect nearly every transit system. These devices are used in change makers and token sellers or as subsystems of vendors and turnstiles.

Transit properties are encountering increased public pressure for special fares, which their equipment, designed for flat fares, cannot handle. An automatic system to process these fares that complements rather than replaces the existing system is needed.

The data presented in this paper indicate that the reliability of recent AFC equipment designs must be substantially improved. Equipment security from internal and external fraud must also be improved and in a manner that does not significantly reduce reliability.

A reassessment of the concept of using magnetically encoded cards as the ticket medium may be worthwhile. This does not imply that those systems could not be made to work if properly

Table 4. Probability that x of nine gates will be operable.

Number of Gates Operable	A = 0.85	A = 0.90	A = 0.95	A = 0.975
3	-	-	-	-
4	0.004 99	0.000 83	0.000 02	0.000 001
5	0.028 30	0.007 44	0.000 49	0.000 04
6	0.106 92	0.044 64	0.006 61	0.001 13
7	0.259 67	0.172 19	0.057 17	0.018 85
8	0.367 86	0.387 42	0.288 53	0.183 75
9	0.231 62	0.387 42	0.647 17	0.796 24
	1.00	1.00	1.00	1.00

Table 5. Gate queuing analysis.

Item	Number of Machines Operating 6	7	8	9
Avg queue waiting time (s)	15.40	1.33	0.41	0.15
Avg flow time (s)	18.18	4.11	3.19	2.93
Probability that a patron will wait more than x seconds to use a machine				
60 s	0.03	N	N	N
30 s	0.15	N	N	N
15 s	0.38	0.001	N	N
10 s	0.51	0.01	N	N
5 s	0.68	0.07	0.01	N
3 s	0.77	0.16	0.03	0.01
2 s	0.82	0.24	0.07	0.02
1 s	0.87	0.37	0.15	0.01

Note: N = negligible.
Service time = 0.36 customers/s; arrival rate = 2.10 customers/s.

specified and developed. However, superior alternatives may exist.

Tickets that are encoded in the form of electrically conductive inks, punched holes, or visible characters readable by both machines and people offer many possibilities. Some of these concepts are already in practice, e.g., in ticket cancelers, at certain parking-lot pass gates, and at supermarket counters.

The design of ticket vendors should also be examined. Several European manufacturers produce vendors that sell magnetically encoded tickets from a roll or a fan fold. This eliminates many of the problems associated with the hopper feeding of thin paper tickets.

The banking industry is developing concepts that could be applied to transit. The use of electronic funds transfer could reduce many of the problems with worn money. Use of more sophisticated coding techniques could greatly reduce the counterfeiting of cards and problems associated with high magnetic-tape bit density.

Farecard design is an area that could have a large impact on system performance. By varying the surface textures, coatings, and shapes of cards, jam rates may be significantly reduced.

Recent vendor designs have tried to reduce the workload in the central counting room by having the vendor perform a stacking function. The value of this policy should be examined, in light of the added costs of vendor reliability. Equipment to aid in the processing of large volumes of money is also required.

As in the rest of the transit industry, procedures or equipment designs for various fare-collection functions vary from one agency to another. Increased standardization might lower the costs of new equipment. Less ambitious fare-collection specifications might permit greater use at lower costs of upgraded products originally developed for the vending industry. Efforts to develop equipment specifications that could be used by several operators may be fruitful.

The need to develop automated equipment to process bus-rail transfers in a graduated-fare system is often cited.

Commuter railroads that charge distance-related fares offer the potential for a successful demonstration of self-service fare-collection techniques.

The cost of the fare-collection system is a hidden element of the construction costs of new rail transit lines. Huge increases in station costs are attributable to the need to provide mezzanines for fare-collection equipment. Techniques to reduce these costs should be investigated.

Fare collection represents between 7 and 31 percent of revenues collected. Operators might achieve large cost savings by means of research and development leading to the development and specification of more effective fare-collection systems.

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