Lindenwold Rail Line and New Jersey Transit Buses: A Comparison

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Rail and bus modes have frequently been compared using theoretical models of hypothetical cities. Because the results of such studies are easily influenced by the author's attitudes toward different modes, there is a need for comparisons of actual transit systems. Two transit systems, rail and bus, serve the New Jersey suburbs of Philadelphia. The conditions under which they operate are generally the same, but the two systems differ greatly. The Lindenwold (PATCO) Line, a single 14.2-mi-long (22.8-km) radial rail rapid transit line with 13 stations, offers high-quality service, including high speed, comfort, reliability, and a strong image. New Jersey Transit (NJT) operates a 562-mi (904-km) network of 26 bus routes on streets, arterials, and freeways, but with low service frequency. Whereas the Lindenwold Line required a substantial investment, NJT buses use existing facilities. The Lindenwold Line attracts 43 percent more passengers and has a 44-percent higher operating ratio in spite of its 20- to 30-percent lower fares. These findings show that concentrated transit service can be more capable of attracting commuters than flexible services that operate on an extensive but low-frequency network. This type of high-quality, intensive service (by rail or bus) also has a much greater potential to influence economic development than the low-investment, extensive bus networks typical for many suburban areas. The results of this study refute the statements that low-investment buses offering flexible services can better satisfy transportation needs in low-density suburban areas than rail systems with limited networks and that new rail transit is not economically justified in most automobile-oriented North American cities. Modern, economically designed rail systems require a considerably higher investment than buses, but they attract many more automobile drivers and other passengers, have superior operating economy, and exert a much stronger positive impact on the communities they serve.

Comparative analyses of transit modes, officially designated as "alternatives analyses," have been performed in recent years in a number of cities, including Pittsburgh, St. Louis, San Diego, Houston, Portland, Ottawa, Calgary, and San Jose. All of these studies lacked experience with different modes in the same locations. One of the basic questions that arises is: Where should each candidate mode (e.g., express bus operations, high-occupancy vehicle or real busway facilities, or rail transit) be used?

RAIL AND BUS SYSTEM COMPARISON: THEORY AND PRACTICE

During the 1960s and early 1970s, a number of theoretical studies comparing modes were published. Most of these studies were sharply disputed for several reasons. First, they were based on hypothetical situations, claimed to be typical for any city. Second, their evaluations were based on minimum cost, whereas differences in quality of service, impacts, and many other important factors were disregarded. Third, they ignored the differences in demands for different modes, although they are often large. Finally, a number of the studies were aimed at finding which mode is better than the others, whereas in reality each mode has its own appropriate application. The question of whether either bus or rail is superior to the other is incorrect to begin with; the relative merit of each system depends on the requirements that have to be met.

Having compared findings of these studies, Deen (*1*) showed the weaknesses of the approaches based on hypothetical cities. Because the models used for these studies are sensitive to various assumptions, the outcomes of such analyses can easily be influenced by the author's attitude toward different modes. Consequently, the results of these studies differed from each other by as much as a factor of 10. Although discredited, hypothetical studies continue to be performed from time to time, often containing the same errors observed before.

Studies comparing planned modes for specific cities are more realistic, because they are based on actual conditions. A remaining problem is that they are still based on projections of the characteristics and impacts of different modes. To get accurate projections (because two or more different modes seldom serve identical corridors), it is necessary to compare different modes serving similar areas in the same or similar cities. A valuable source of information on bus transit systems in different cities was published by Wilbur Smith and Associates (*2*), and Pushkarev (*3*) gave an excellent review of rail transit systems and their roles in U.S. cities. Vuchic and Stanger (*4*) made a comprehensive comparative analysis of rail and bus systems using the specific examples of the Lindenwold Line and the Shirley Busway, which have extensive similarities, so that the differences in their services and impacts can be largely assigned to the characteristics of the rail and bus modes.

COMPARISON OF RAIL AND BUS SYSTEMS SERVING THE SAME AREA

As in the Vuchic and Stanger study (*4*), two existing, operating systems will be compared. However, instead of two systems that in many ways represent the most advanced forms of their modes (the Lindenwold, rapid transit, and the Shirley, express busway), two modes of services in the same suburban

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area—modern rapid-transit and a minimum-investment bus system using streets, arterials, and freeways—are compared. Therefore, new insights on the characteristics of rail and bus transit modes in roles typical for many North American cities should be provided.

METHODOLOGY

The methodology applied here is similar to the one used by Vuchic and Stanger (*4*). The two systems and their characteristics are presented, including both quantitative and qualitative data. Then, the performance and characteristics of the two systems are analyzed by individual parameters, classified into three groups by the interested parties: passengers, operator, and community. The selection of these parameters may vary somewhat with local conditions. The following have been selected as the most important parameters:

Passenger	*Operator*	*Community*
Spatial availability	Area coverage	Quality of service
Temporal availability: Frequency	Frequency Speed	System impacts
Speed or travel time	Control and reliability	
Reliability of service	Costs, revenues, and operating ratios	
User costs		
Comfort	Capacity	
Convenience	Side effects	
Safety and security	Passenger attraction	

On the basis of the comparative analyses of individual parameters, an overall comparison of the two systems is made. Finally, the differences inherent in the two modes are discussed.

SERVICE AREA

Both the Port Authority Transit Corporation's (PATCO's) Lindenwold Line and New Jersey Transit (NJT) buses serve the New Jersey suburbs of Philadelphia (Figure 1). Their major role is to provide transportation between these suburbs and center-city Philadelphia and Camden. They are also used for trips between suburban areas of New Jersey.

Center-city Philadelphia, defined as the area between the Delaware and Schuylkill Rivers and between Vine and South Streets, has an employment of approximately 238,000 and contains stores with some 4.8 million ft^2 (0.45 million m^2) of leased retail area. Downtown Philadelphia also has a large number of restaurants, cultural and historic attractions, sports events, and other activities. As such, it is by far the most dominant generator of trips from the suburbs of the entire Delaware Valley region, which had a population of 5,148,000 in 1987.

Camden, the largest traffic generator in the New Jersey suburbs, was a city with a population of 83,000 in 1987. It is the seat of Camden County; in addition to governmental offices and legal services, it has some light industries and educational institutions.

The suburban area consisting of Camden, Burlington, and Gloucester counties has a number of mature and stable townships, as well as commercial strip developments, industrial areas, and recently developed low-density residential areas. Their overall population densities in persons per square mile (persons per square kilometer) are as follows: Camden, 2,096 (5,426); Gloucester, 589 (1,525); and Burlington, 436 (1,129). Automobile ownership for the three counties is 1.48, 1.58, and 1.65 cars per household, respectively. Thus, these are rather typical, medium- to low-density automobile-oriented suburbs.

The basic data on the service area and the two transit systems are presented in Table 1.

Rail System: The Lindenwold Line

The Lindenwold Line has four stations in center city Philadelphia: one at Market and 8th streets and three along Locust Street, which is parallel to Market, three blocks south. Two of these stations provide convenient transfer to the two rapid-transit lines in Philadelphia. A two-block connection through a shopping mall links the Lindenwold Line to Market East Station, which serves the entire regional rail system, consisting of seven diametrical lines.

In Camden, the Lindenwold Line has two stations in the center city; one is part of a major new multimodal transportation center. From Camden, the line proceeds along a southeast corridor through several municipalities (Collingswood, Haddonfield, and Voorhees), as shown in Figure 2. The seven stations along this section have park-and-ride (P&R) facilities with a total capacity of 12,571 spaces. Lindenwold Station, with the largest P&R facility, has 3,318 parking spaces and a transfer to the National Railroad Passenger Corporation's (AMTRAK's) new Atlantic City line. A detailed description of the PATCO line is given by Vigrass (*5*).

Bus System: New Jersey Transit

NJT is a statewide public transit corporation. It was created in 1979 by an act of the state legislature with the charge to provide transit services throughout the state by operating, contracting for, and subsidizing services in the public interest.

NJT serves Camden, Gloucester, and Burlington counties with an extensive network of 20 lines that encompass 26 routes or branches. These routes are plotted in Figure 1. Eleven major lines with 17 branches converge on Ben Franklin Bridge and proceed to Philadelphia, along Market Street to City Hall, then up to Vine Street and back to the Ben Franklin Bridge. Thus, they serve the city's core with several stops on Market Street between 6th and Broad streets.

NJT bus lines also serve Camden quite extensively; five lines terminate in Camden, and several lines from the suburbs to the Ben Franklin Bridge go through downtown Camden, increasing coverage and service frequency in that area.

As shown in Figure 1, NJT bus lines form an extensive multidirectional network that also provides many trips among suburban townships and commercial areas, in addition to the dominant travel volumes into and out of Philadelphia and Camden. Several of these lines serve as feeders to the Lindenwold Line. The lengths of the lines vary from 7 to 49 mi (11 to 79 km), and the network length is 562 mi (904 km).

The NJT bus network has approximately 1,500 stops in these three counties. There is little demand for P&R, so the

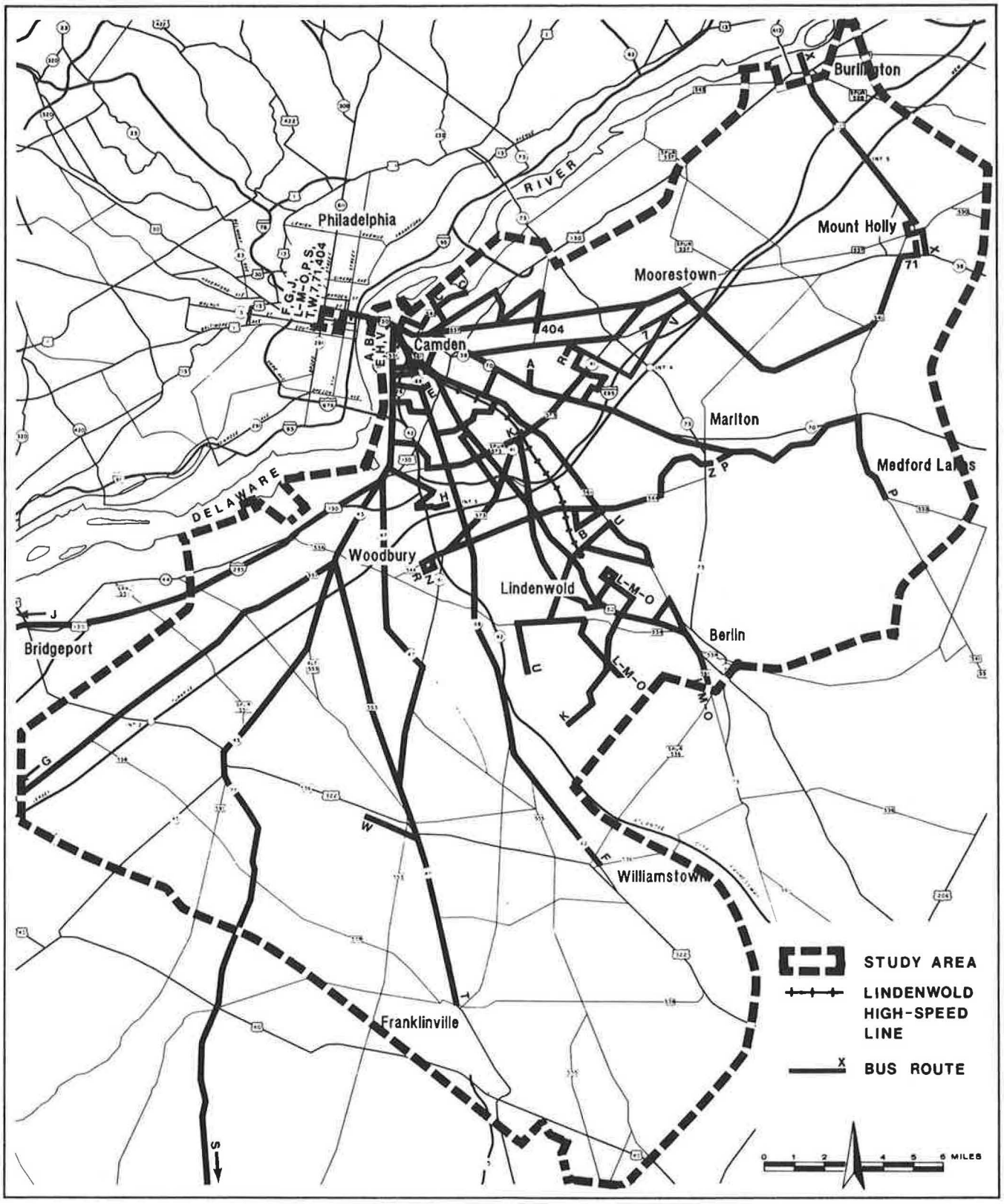

FIGURE 1 Philadelphia-Southern New Jersey study area with the Lindenwold Rail Line and NJT Bus network.

TABLE 1 BASIC AREA AND TRANSIT SYSTEMS CHARACTERISTICS

Characteristic	Lindenwold Rail Line	NJT Buses
Service area	One of several radial corridors in Camden County	Several corridors and most of Camden, Burlington and Gloucester Counties
Area size (mi^2/km^2)	130/337	593/1536
1980 Population	471,650	794,777
Type of lines	Radial via bridge to Philadelphia	Radials into Camden and via bridge to Philadelphia; cross-town, branches, rail feeders
Technology	Rail rapid	Buses on streets arterials, freeways
Type of service	Local, some express runs	Local and express
Network length (mi/km)	14.2/22.8	562/904
No. of stations/stops	13	~1500
Park-and-ride spaces	12,571	~ 600
Submodal split[%]		
Walk, bicycle	11	63-77
Feeder transit	9	15-28
Kiss-and-ride	43	10-20
Park-and-ride	37	
CBD distribution	4 stations, transfers to SEPTA lines	Stops along 6th and Market East Streets

capacity of P&R facilities is only about 600 spaces; a certain number of transit riders park their cars along the streets in the vicinity of bus stops. Extensive technical details on NJT buses are to be given in a report by NJT (*6*).

Table 2 presents a summary of the operating statistics of the two systems.

COMPARATIVE ANALYSIS OF THE LINDENWOLD LINE AND NJT BUSES

Individual parameters of the two systems will be compared. A parameter (or requirement) will be briefly defined; then each system will be examined with respect to it, quantitatively or qualitatively. Some requirements that are difficult to separate clearly will be evaluated together. The comparisons will be summarized in an overall comparative analysis of the two systems.

Passenger Requirements

Spatial and Temporal Availability

Availability is the basic passenger requirement for transit service use. Three aspects of availability can be defined: first, a person's ability to use a system; second, spatial availability, which involves both the passenger's ability to get to the system and the requirement that the transit service goes to the necessary destination; and third, temporal availability, which is the frequency of service or its inverse, the headway.

Although the availability of automobile travel depends on vehicle ownership and the owner's ability to drive, transit systems are generally available to all persons; in this respect, bus and rail systems are the same. The availability of stations is influenced by the available feeder modes, such as automobiles, bicycles, or feeder buses. For a given trip, the availability of service depends largely on the extensiveness of the

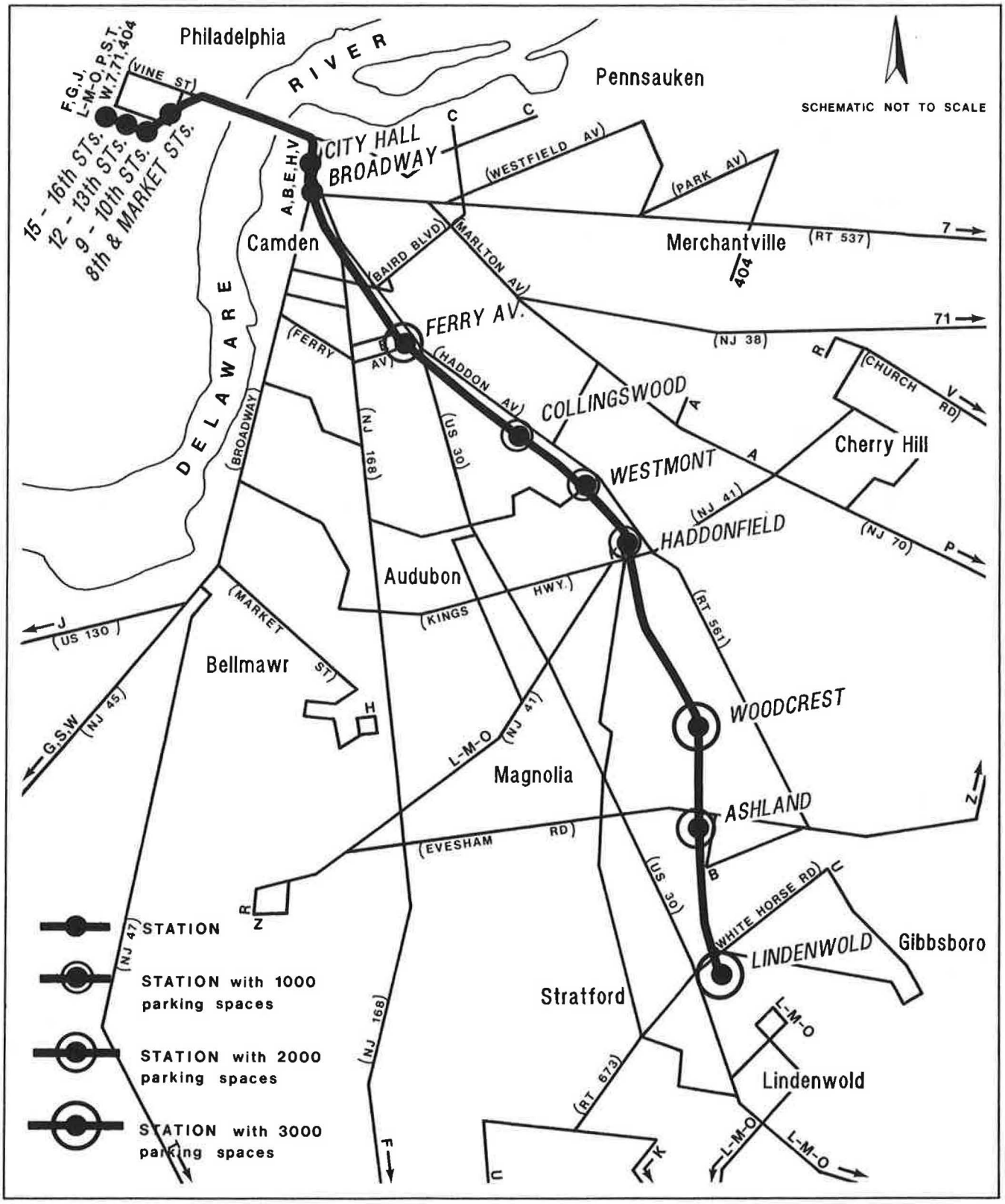

FIGURE 2 The Lindenwold Line alignment with stations and P&R capacities.

TABLE 2 1987–1988 OPERATING STATISTICS: LINDENWOLD RAIL LINE AND NJT BUS SERVICES

Category of Routes	No. of Trunks/ Total Branches	Passengers /Weekday	Cost/Veh-Hour	Revenue/ Veh-Hour	Operating Ratio
Lindenwold Rail Line	1/1	39,500	125.10	97.03	0.78
Philadelphia Commuter	11/17	22,230	40.19	23.31	0.58
Camden Area	5/5	1,661	37.10	12.60	0.34
Camden Locals	4/4	3,725	35.74	17.87	0.50
Total Intra New Jersey	9/9	5,386	~36.00	~16.00	0.44
Total NJT Buses	20/26	27,616	~39.00	~21.00	0.54

transit network. Frequency of service must be analyzed for peak and off-peak hours.

Lindenwold The PATCO Line provides only a line-haul service with few stations. Its outlying section consists of seven stations with an average spacing of 1.5 mi (2.4 km) and the longest spacing of 2.4 mi (3.86 km). For area coverage, this line relies heavily on feeder systems. The most important feeder mode is the automobile, which brings 43 percent of the passengers as kiss-and-ride (K&R) and 37 percent as P&R users. Twenty bus lines (both feeders and regular lines) come to the Lindenwold Line stations at various points on their routes. The transfer is physically convenient, and some discount in joint fares is available. Bus riders, walkers, and bicyclists amount to approximately 11 percent of the Lindenwold Line passengers.

The two stations in Camden, which are downtown, are served by many of the bus lines. In Philadelphia, a short distribution segment is within the center city, but the stations are two to four blocks away from the main employment centers and shopping areas. Convenient transfers and reduced fares provided for transfers to Southeastern Pennsylvania Transportation Authority (SEPTA) lines for inbound round trips tend to offset this handicap.

The Lindenwold Line has an extremely high performance with respect to frequency of service. During the peak hours, some headways are as short as 2.5 min; during the base periods, typical headways are 10 min; and during the owl service at night, 30-min headways are maintained. In addition, some of the peak-hour trains offer limited express runs on individual sections of the line. The line has about a 100-percent reserve capacity, because it can be operated at 2-min headways instead of the present 4-min headways.

NJT Buses The spatial availability of NJT buses is excellent. The network consists of 20 trunk lines branching into 26 routes, with considerable overlapping on individual segments. The exact number of stops is not known, because many stops in outlying areas are rather informal, but the network has an estimated 1,500 stops and stations in southern New Jersey. Because it is so extensive, this network is also good in serving a large number of origin-destination pairs.

In service frequency, the system is poor. The busiest lines offer peak-hour headways of 12 min and base headways of 1 hr; there is no service between 12:00 midnight and 5:00 a.m. The service frequency is considerably better on the sections where several lines overlap for some distance. The maximum frequency (up to 60 buses per hour) occurs on the Ben Franklin Bridge to Philadelphia. This frequency, however, is not significant for passengers, because only a few of these buses will be appropriate for each destination, because of their branching toward New Jersey suburbs.

It is difficult to obtain precise data on the submodal split of passenger access to NJT buses in New Jersey, but surveys have shown that walking accounts for 63 to 77 percent of the access to individual lines; 15 to 28 percent of the passengers transfer from other buses, whereas P&R use is rather negligible. There are several P&R and some unofficial parking areas; their total capacity is estimated to be 600 spaces.

In downtown Philadelphia, NJT buses distribute passengers along Market Street to City Hall and then return via Vine Street to the Ben Franklin Bridge. Thus, the distribution of buses is in the heart of the city, close to many destinations.

Comparison The two systems are drastically different with respect to availability of service. The Lindenwold Line has few stations but an excellent feeder system, dominated by

automobile access. The line offers excellent frequency at all times of day. NJT buses, on the other hand, have an extensive network with many lines and stops, but have poor frequency of service (Figures 3 and 4).

Speed or Travel Time

Door-to-door travel time consists of five elements: access, waiting, travel, transfer, and departure times. The relative weights of time intervals vary, because passengers perceive them differently. On the basis of various studies reported in literature, a factor of 2.5 for waiting and transfer times is used here to obtain perceived travel times.

Lindenwold For a typical automobile commuter residing 3 mi (4.8 km) beyond the Lindenwold Station, an average of 47 min are required for the morning peak-hour drive to the Philadelphia central business district (CBD), including parking. The same journey using the Lindenwold P&R or K&R facilities requires 35 actual minutes or 42 perceived minutes. The average travel speed on the line is 35.5 mph (57.1 km/hr); the design speed is 75 mph (121 km/hr).

NJT Buses Average travel speeds on NJT buses range from 12 to 40 mph (19 to 64 km/hr), but they are most often in the range of 15 to 25 mph (24 to 40 km/hr). The time it takes people to access the bus stops is in most cases rather short. However, buses travel more slowly than other traffic because of passenger stops. Moreover, buses are also subject to highway traffic delays. The typical commuter trip analyzed earlier would take approximately 70 min by NJT bus service.

Comparison As the sample trip and Figure 5 show, the Lindenwold speeds and travel times are clearly superior to those of NJT. The Lindenwold Line provides faster service than the competing travel by private automobile, whereas buses are inferior to cars in travel times.

Reliability of Service

Passengers consider reliability, or schedule adherence, as one of the most important elements of transit service. It is measured as the percent of transit vehicle arrivals at their destination within 0 to 5 min of the scheduled time. Reliability depends on many factors, the single most important one being the type of right-of-way: a separated right-of-way always provides a much higher reliability of service.

Lindenwold Having an exclusive right-of-way and good operational control, the PATCO line provides extremely reliable service. From 1980 to 1986, the average punctuality of this service fluctuated between 98.34 and 99.10 percent, which is typical for well-operated rapid-transit rail systems (*7*).

NJT Buses NJT buses operate in mixed traffic, except for a bus lane in center-city Philadelphia. Yet, in a personal interview, an NJT official claimed that the service reliability is between 97.02 and 98.01 percent.

Comparison The PATCO line provides a higher reliability of service, although the difference is not as great as the typical difference between rapid-transit rail lines and buses on streets, because of the good performance of NJT buses.

User Costs

Passengers are sensitive to the direct, out-of-pocket costs they pay for individual trips. Transit fares represent such a cost, as do payments for parking or tolls. Passengers sometimes look also at average total costs. With respect to these costs, the two systems are drastically different.

Lindenwold The Lindenwold Line has a graduated fare that goes from the basic fare of $0.75 to the maximum fare of $1.60. Close-in portions of P&R lots involve a parking charge of only $0.25. Thus, the out-of-pocket costs are low even for most riders who use an automobile for access (i.e., all K&R and many P&R users). However, for the riders who own an automobile only for the purpose of driving to the line, that involves substantial costs. On the basis of U.S. Department of Transportation reports, the average annual costs of owning and driving an automobile amount to approximately $3,000.00, or $8.00 per day. Thus, for the riders who own an automobile only for access to the rail line, the indirect cost usually exceeds the out-of-pocket cost for their travel to Philadelphia.

NJT Buses Bus fares are also graduated, from $0.90 for Zone 1 to $5.20 for Zone 10 (in 1987). The Lindenwold terminal falls in Zone 4, for which the bus fare to town is $2.35 (Figure 6). Thus, the minimum fare on the buses is 20 percent higher than on rail, whereas the maximum comparable fare is 42 percent higher. Because most passengers approach bus stops on foot, however, their indirect cost is much lower than the costs for rail riders.

Comparison The Lindenwold Line involves a considerably lower out-of-pocket cost, but the average total travel cost for its users is higher than for NJT bus riders.

Comfort

The paramount elements of comfort are the availability of a seat and the quality of ride, both of which affect a user's ability to read or write. The physical comfort of the seat, its shape, vehicle entrances and exits, air conditioning, jerk and noise levels, and the image of patrons relative to a user's self-image are also contributing factors.

Lindenwold Although there is ample seating in the vehicles in off-peak hours, in some peak-hour trains 20 to 30 per-

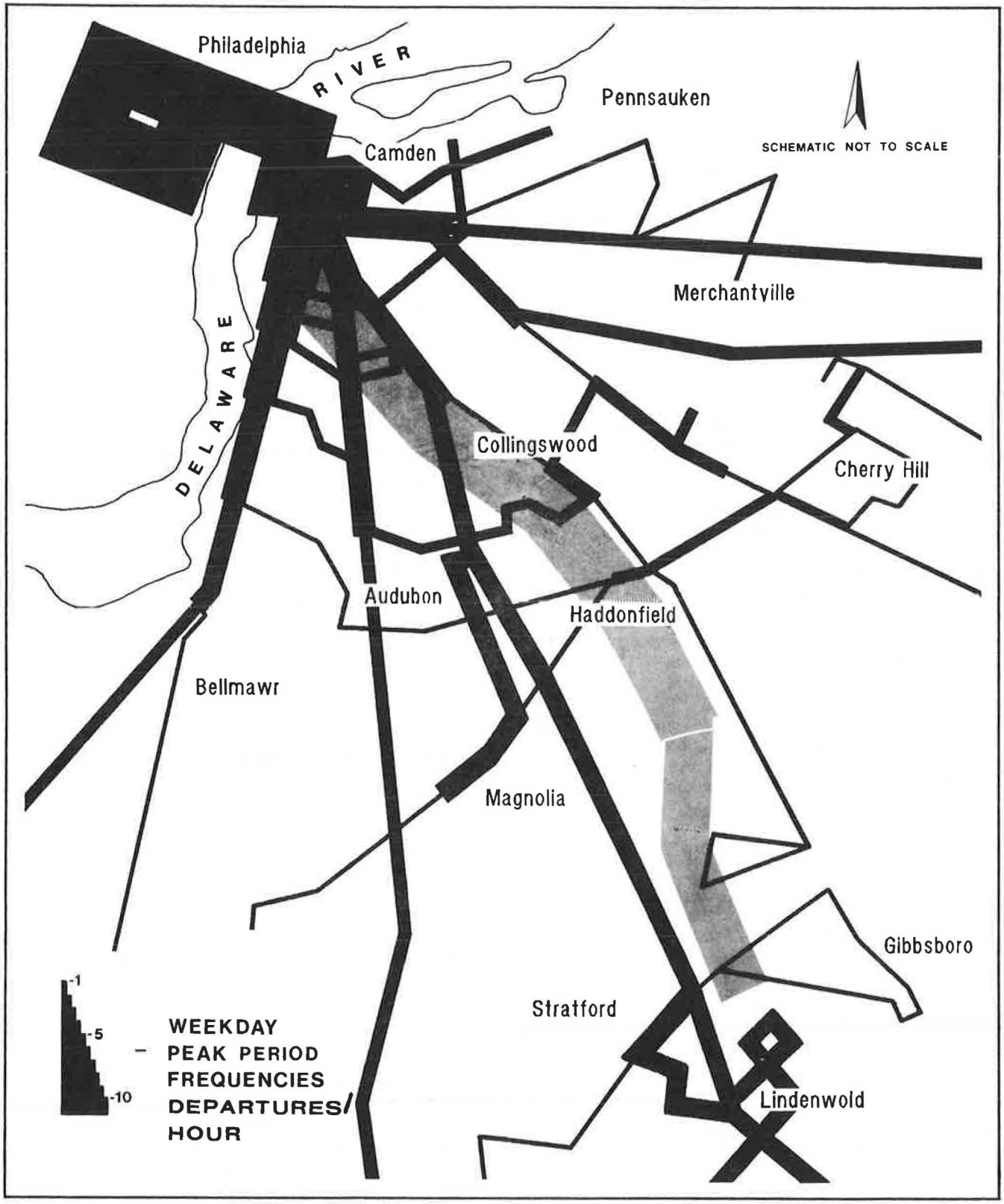

FIGURE 3 Peak-period service frequencies: Lindenwold Line and NJT Buses.

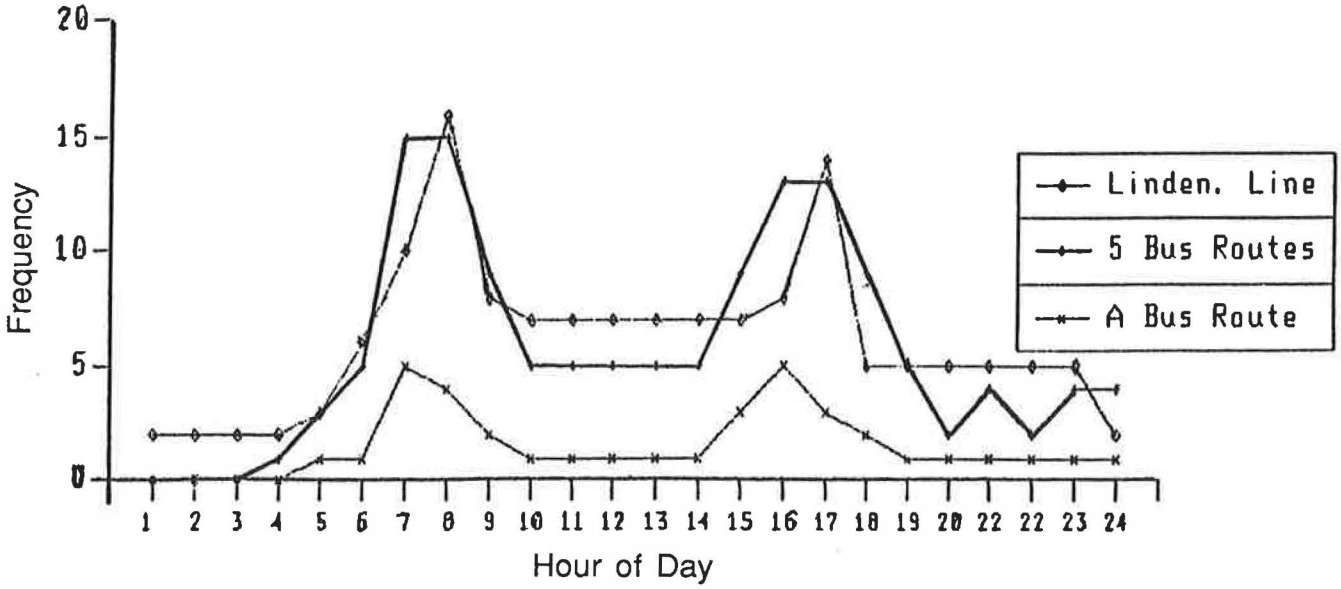

FIGURE 4 Comparison of frequencies during different periods of day.

cent of the passengers stand during about 10 min of travel. The seats themselves are wide and comfortable. The car interiors are plush, air conditioned, clean, and lighted, affording the opportunity for reading. Vehicle acceleration is rapid but smooth. Large windows offer visibility in all directions, contributing psychologically to the attractiveness of this service.

NJT Buses Buses are less comfortable than rail vehicles, because the seats are tighter, the ride is more jerky, and buses are subject to unpredictable influences of other traffic. NJT buses are air-conditioned, and there are usually no passengers standing. The visibility is not as spectacular as that of the Lindenwold Line.

Comparison With the exception of standing, which is more common on the rail line than on the buses, all components of comfort are superior on the Lindenwold Line.

Convenience

Although most components of comfort are related to the vehicle, convenience refers to the overall transit system. Lack of transferring is a great convenience, as are good off-peak service, clear system information, well-designed and protected waiting facilities, sufficient parking (if required), and high quality of service. By its nature, convenience represents a qualitative characteristic of transit systems.

Lindenwold The PATCO line requires a transfer from access modes for 89 percent of its passengers. Parking around stations represents a great convenience to users who come by car. Stations are pleasant and offer convenient access to platforms and a high quality of service. Information about the service is clear, simple, and always available. Thus, although most passengers must transfer from different modes, the convenience of using the PATCO line is excellent.

NJT Buses With its combination of local and express services, NJT offers what is often pointed out as a great convenience of bus services for low-density areas: extensive area coverage and no need for access modes. However, the potential user is faced with the problem of discovering which line goes where, at what time (long headways), where the stops are, and how much he or she has to pay. Thus, the convenience of NJT buses is low.

Comparison The convenience of the large network of bus routes and many stops is greatly outweighed by the convenience of the high-quality service from distinct, well-designed stations with frequent service for which no schedule is needed. Thus, the Lindenwold Line is much more convenient to use than NJT buses.

Safety and Security

Safety generally refers to the absence of accidents; security is protection from crime.

Lindenwold Being a typical modern rail transit system, the PATCO line has redundant automatic safety devices that ensure extremely high operating safety. Except for a few light car collisions in maneuvering and a couple of derailments at low speed, the line has never had an accident. No passenger has been killed on the line by a train accident in the 22 years of its operation. The line's security arrangements include continuous closed-circuit television monitoring of all stations coupled with a public address system, and a police force that guards the station areas and overnight trains. These arrange-

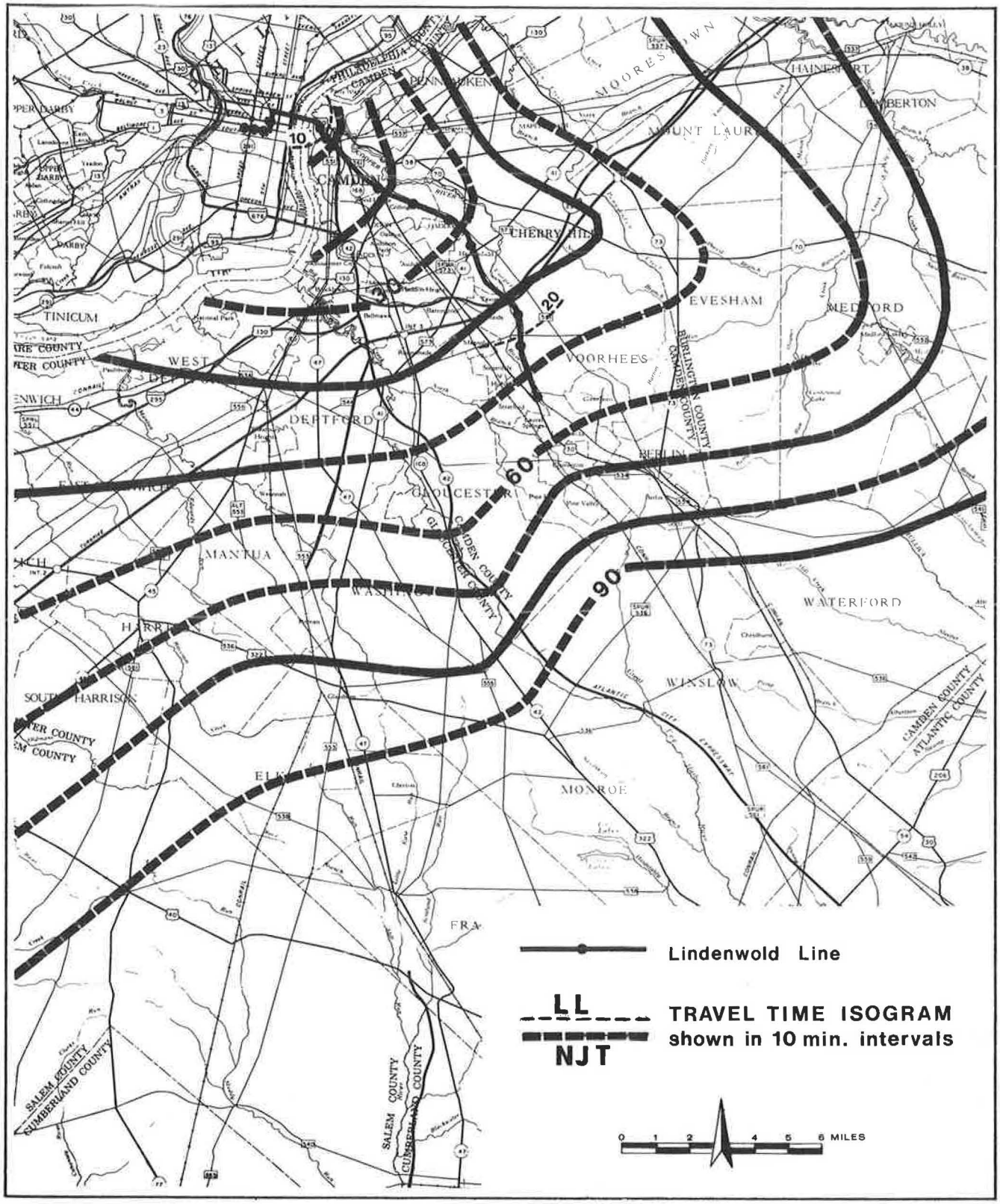

FIGURE 5 Isochrones of travel to Philadelphia CBD by Lindenwold Line and NJT Buses.

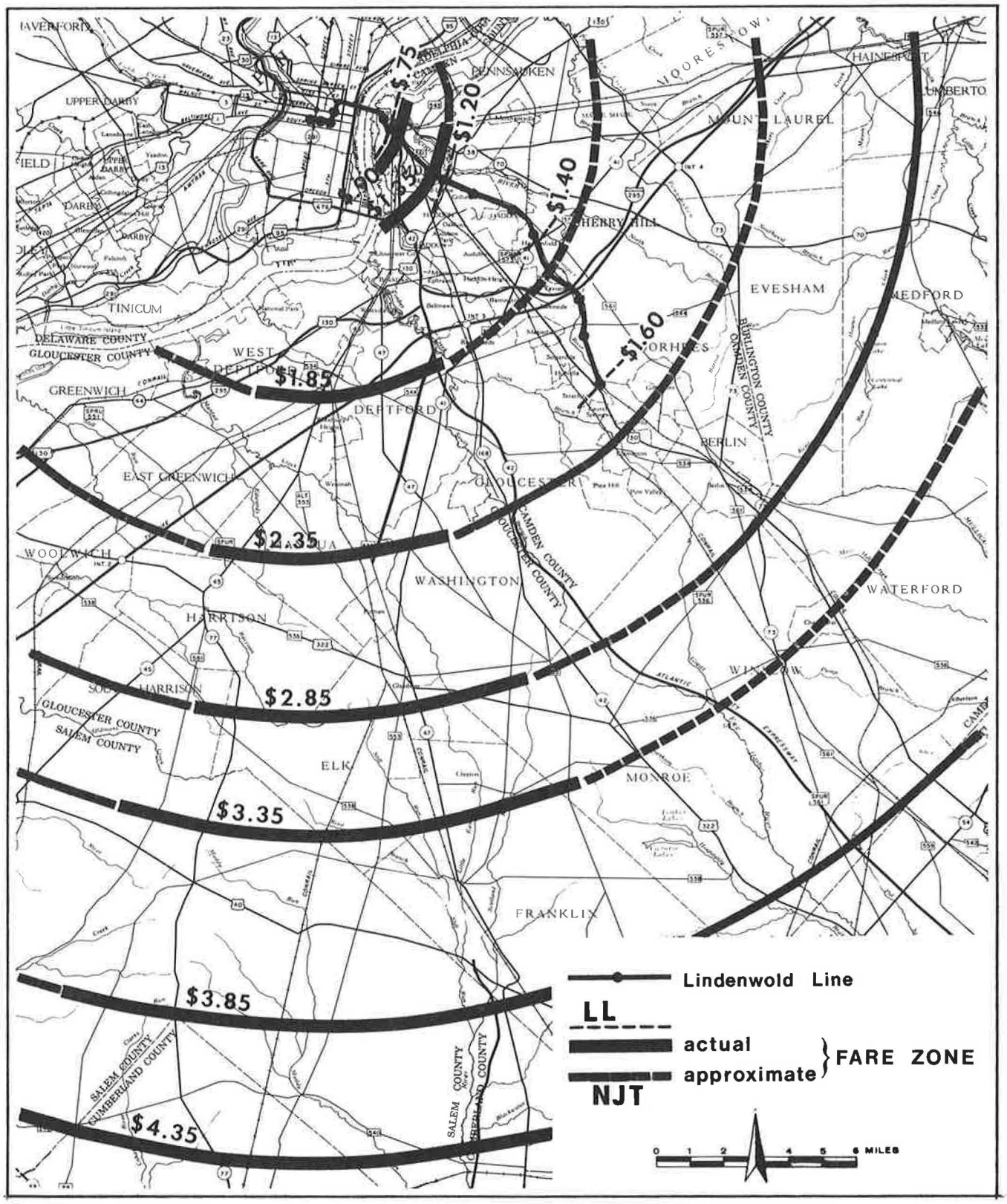

FIGURE 6 Lindenwold Line and NJT Bus fares to Philadelphia CBD.

ments have produced a high security record and good public image.

NJT Buses Although bus service is relatively safe, the buses are in highway traffic and are involved in some accidents. With respect to crime protection, passengers like the presence of the driver in the bus, but waiting for a bus at a curbside location in lonely areas, particularly at night, is a feature that many passengers find objectionable.

Comparison In both safety and security, the Lindenwold Line is excellent. The NJT buses have a good safety record, although not as high as that of the Lindenwold Line; their security has a far lower image.

Operator Requirements

Area Coverage

Lindenwold Taking 5- to 10-min walking distances (i.e., 1,250 to 2,500 ft or 400 to 800 m) as measures of area coverage, the nine Lindenwold stations in New Jersey have a coverage of 1.58 mi^2 (4.10 km^2) or 6.34 mi^2 (16.42 km^2), respectively. However, because nearly 90 percent of its passengers use automobiles for access, it is more realistic to consider the area from which the majority of P&R and K&R passengers come to the stations. Surveys of these passengers (*8*) have shown that they approach the stations from an area of approximately 130 mi^2 (337 km^2).

NJT Buses With their frequent stops along the routes, it can be considered that the area covered by these services represents a strip of 5-min walking distances on each side of the bus routes. Measurements show that the total coverage by NJT buses in New Jersey suburbs amounts to 593 mi^2 (1,536 km^2).

Comparison With the length of all bus routes being 562 mi (904 km), as compared to the Lindenwold Line length of 14.2 mi (22.8 km), the bus network is nearly 40 times more extensive. Its area coverage, even if it is assumed that buses cover only walking distance areas whereas the rail system covers an area of access by automobile, is about 4.5 times greater.

In center-city Philadelphia, buses offer somewhat better coverage, because they follow an alignment through the heart of the city, whereas the Lindenwold Line runs three blocks south of this alignment; on the other hand, the Lindenwold Line offers better integrated transfers to SEPTA's rail network; it can therefore be considered that the distributions of the two systems in the center city are comparable.

In conclusion, the outlying parts of the two networks differ greatly, buses offering vastly better area coverage.

Frequency

Lindenwold Having a single line that generates dense travel, PATCO operates six trains at 10- to 12-min headways in the base period. This schedule requires six train operators. As the volume increases, trains can be lengthened from one to six cars, so that the line's capacity can be increased sixfold with the same personnel. Even the frequent peak-hour service increases labor requirements only to about 15 operators.

NJT Buses NJT buses mostly serve lightly traveled routes, and another driver must be added for each service or 45-space capacity. With the high marginal cost of providing service and its extensive network, NJT cannot provide good frequency.

Comparison Being an intensive line with high trip attraction and having the inherent high and flexible labor productivity of rail modes with a much lower peak-to-base ratio of labor requirement, the PATCO line offers a much higher frequency of service than any NJT bus route, as well as the entire NJT network.

Speed

From the operator's point of view, operating and round-trip speeds are important, because they directly affect the required fleet size and operating cost.

Lindenwold The Lindenwold Line has travel times of 24 to 25 min (varying between off-peak and peak times) on its 14.2-mi (22.8-km) length, bringing the average operating speed to about 35 mph (56.3 km/hr).

NJT Buses These routes have variable speeds, ranging from 10 to 35 mph (16 to 56 km/hr).

Comparison The Lindenwold Line is greatly superior to NJT with respect to speed. Only the longest express bus routes with few stops match the speed of the Lindenwold Line; most of the others have considerably lower operating speeds.

Control and Reliability

Lindenwold The PATCO line's right-of-way is fully controlled, without any contact with other traffic; its stations and trains are under supervision from a central control center by model board and closed-circuit television. Operations are monitored at all times, and information and data on the entire system are available in great detail.

NJT Buses The buses are subject to street traffic delays, and there is no central control for stops or the locations of

buses. General information on performance of different routes, ridership, and other statistical data is rather limited.

Comparison The two systems differ in their method of operation, degree of control, and reliability of operations. The Lindenwold Line is greatly superior in its control and the resulting reliability of service. For purposes of analyses of operations, performance, costs, passenger characteristics, and other elements, the Lindenwold Line represents a far superior system.

Costs, Revenues, and Operating Ratios

Lindenwold The Lindenwold Line was constructed in the late 1960s by upgrading an existing Philadelphia-Camden rapid transit line and constructing a 10-mi (16-km) extension to Lindenwold. The cost was $94 million. Subsequent construction of a new station, platform extensions, the purchase of 46 additional cars, and several other upgrades amounted to probably doubling of the initial investment. Detailed statistical data about the Lindenwold Line show that its operating costs have gradually increased from $4.3 million in 1970 to $19.8 million in 1988. Revenues have increased during the same period from $4.2 million in 1970 to $15.4 million in 1988. The operating ratio, 0.78 in 1989, has fluctuated between 0.77 and 0.95, depending on the times of fare increases. Each increase leads to an improvement in the operating ratio, followed by its gradual decrease as inflation progresses.

NJT Buses Because buses use existing streets and highways, no direct infrastructure investment cost can be assigned, with the exception of some station and terminal facilities. As Table 2 shows, operating ratios for different route categories vary between 0.34 and 0.58 and average about 0.54.

Comparison A comparison of the two systems with respect to costs is quite drastic. The Lindenwold Line involved an incomparably higher investment cost, but it shows a persistent ability to cover by passenger revenues a much higher share of its operating costs. Its operating ratios of 0.80 to 0.85 include expenses for the entire PATCO system. Operating ratios for buses are much lower: computed on a direct-cost basis only (i.e., excluding overhead), they amount to only 0.40 to 0.60.

Capacity

Lindenwold Several trains on the Lindenwold Line operate during the peak hours with headways of 2.5 min. This operation represents an offered capacity rate of 21,600 spaces per hour. It is estimated that the line actually carries up to 15,000 passengers per hour.

NJT Buses NJT buses offer a capacity of only 3,000 to 4,000 spaces per hour, but this capacity could be increased if the demand were greater. The capacity of this network is difficult to define physically, because buses use multilane highways and streets. The bottleneck would first appear at major bus stops in downtown Philadelphia.

Comparison The capacity of the Lindenwold Line is distinctly superior to that of NJT.

Side Effects

The most important negative effects on nonusers and the environment for which the operator is responsible are aesthetics, noise, and air pollution.

Lindenwold The sections of line in tunnels and on the bridge have no external impacts; the elevated structure is aesthetically satisfactory, noise levels are low, and air pollution is nonexistent. However, although many underpasses are provided, the line has a certain dividing effect on the area.

NJT Buses Buses in streets are aesthetically satisfactory, but the noise and air pollution caused by them are objectionable, particularly in downtown Philadelphia and Camden.

Comparison NJT buses produce somewhat greater direct negative side effects than does the Lindenwold Line.

Passenger Attraction

The overall ridership attracted by the two systems will be discussed in the section on community requirements. With respect to transit operators, the two systems are quite different in their passenger attraction. NJT buses provide the basic service in and between New Jersey communities, and this includes many local shopping, school, and other trips. The buses attract a certain number of commuters to Philadelphia, but they are not very competitive with the automobile. This is obvious from the low demand for P&R facilities.

The Lindenwold Line, on the other hand, does not provide many local trips because of its long station spacings and limited area coverage. However, it is highly competitive with the automobile and much more capable of diverting trips from highway travel, as shown by the large number of people who access its stations by automobiles. Thus, the PATCO line has a different ridership and must maintain a high quality of service to remain competitive with the automobile.

Community Requirements

Quality of Service

The preceding paragraphs show that the rail and bus systems offer different types of services to the communities they serve.

The Lindenwold Line offers a limited network—a single line—but its service is of the highest quality. Its reliability, speed, comfort, and overall image are excellent. Buses also serve travelers into Philadelphia and Camden, but surveys show that the average income of their commuters is only 74 percent of the income of PATCO line commuters; in addition, the buses serve as the basic carriers of the local population, among whom 75 percent have annual incomes of less than $20,000. Thus, buses also provide a socially important basic transit service.

NJT buses provide an extensive network of services, but with a low frequency and a much weaker image than that of the Lindenwold Line. This difference explains why the Lindenwold Line, with service to only 13 stations, attracts a daily ridership of 39,500 passengers, whereas the 26 bus routes, with a network length of 562 mi (904 km) and approximately 1,500 stops, attract only 27,600 passengers a day, or 43 percent less.

The difference between the two systems is even greater than these numbers show. The NJT bus figures include a large number of short trips within the New Jersey communities. Thus, if commuting into and out of Philadelphia and Camden are separated, where the two systems closely overlap, the Lindenwold Line attracts an even greater share. Also, due to the longer average trip length on the line, its transportation work (in person-miles) is greater than the corresponding transportation work on buses. Unfortunately, exact numbers on this comparison cannot be determined, because the average trip length on the buses is not known.

System Impacts

Due to its strong attraction of automobile drivers, the PATCO line has a major impact on the area it serves. By diverting between 10,000 and 12,000 automobile round-trips per day from highways, the line decreases congestion in the corridor and reduces parking needs in central urban areas, particularly downtown Philadelphia, by this amount. If the line did not exist, some of its riders would not go to Philadelphia at all; however, even those that are induced represent benefits to the riders and the areas to which they go. Thus, the line benefits both users and other travelers and has a substantial impact on activity in the area through increased mobility. Boyce (*8,9*) offers detailed studies of these impacts of the PATCO line.

NJT buses also attract some commuters from automobiles and decrease highway traffic and parking needs in downtown Philadelphia. However, this impact is considerably smaller than the impact of the Lindenwold Line.

Several studies have shown that the Lindenwold Line has had significant impacts on land values, commercial developments, and land uses. NJT has not demonstrated any such impacts, primarily because of its lower level of service than the Lindenwold Line and its lack of infrastructures that have a particularly strong impact on investments and transit system image.

In conclusion, the PATCO rail line has a much greater positive impact on the areas it serves than NJT buses; however, the latter provide an essential social service.

SUMMARY

The results of the parametric analysis and comparison of the two systems are summarized in a simple form in Table 3.

Similarities Between the Two Systems' Roles

The Philadelphia suburbs in southern New Jersey represent an excellent area for the comparison of rail and bus transit modes. Because both PATCO and NJT serve the same general area, there are no significant differences in the external influences that often make this kind of comparison difficult. The type of economy, land-use patterns, population characteristics, incomes, automobile ownership, and, of course, topography and climate, are the same or nearly the same for both modes. Both systems have the same basic role: to serve travel into and out of Philadelphia and Camden. The buses also serve local travel needs among New Jersey communities, which the Lindenwold Line cannot do effectively. Nevertheless, the two systems differ drastically in the quality of service they offer and in their impacts.

Differences

The major service differences that the Lindenwold Line and NJT buses offer are as follows.

1. *Networks*: The two systems represent two extremes in the tradeoff between area coverage and frequency. Lindenwold has a limited area coverage but high service frequency; the buses offer extensive area coverage with low frequency.
2. *Rights-of-way*: The Lindenwold Line has a fully controlled, Category A right-of-way, which allows a high degree of automation in the operation of trains and stations. Buses operate in right-of-way Category C: they use streets and freeways and operate manually in mixed traffic. This difference results in Lindenwold's much higher performance and labor productivity and, consequently, much lower operating costs.
3. *Vehicles and stations*: The ride on PATCO trains is so comfortable that passengers' need to stand is not highly objectionable. Buses offer comfortable seats to every passenger, but the riding comfort and spaciousness are lower than those of rail vehicles.

It is clear from the preceding comparison that the Lindenwold Line offers a service that, although limited to few points, is so distinct and has such a high level of service, convenience, and reliability that it successfully competes with the automobile. The extensive use of P&R and K&R facilities proves that clearly. NJT buses, on the other hand, provide services that are tailored to various types of travel. Individual routes cover many localities and neighborhoods, stop at dozens of locations, operate locally and in express modes on freeways, and make use of typical urban transit buses as well as comfortable suburban buses, without standees. However, their dispersal and low frequency make the buses difficult to recognize and use; their services have a weak image, and therefore they do not compete successfully with automobile travel.

TABLE 3 SUMMARY COMPARISON: LINDENWOLD RAIL LINE AND NJT BUSES

Requirement	Lindenwold	NJT Buses	Higher Rated System
Passenger:			
Availability - Spatial	Fair*	Very good	NJT Buses
Availability - Temporal	Very good	Very poor	LL Rail
Speed/Travel Time	Very good	Fair	LL Rail
Service Reliability	Very good	Good	LL Rail
User Costs	Very good**	Fair	LL Rail
Comfort	Very good	Good	LL Rail
Convenience	Good	Very poor	LL Rail
Safety and Security	Very good	Good	LL Rail
Operator:			
Area Coverage	Good (with auto)	Very good	NJT Buses
Frequency	Very good	Very poor	LL Rail
Speed	Very good	Fair	LL Rail
Control and Reliability	Very good	Fair	LL Rail
Cost: Investment	Poor	Very good	NJT Buses
Operating Ratio	Very good	Fair	LL Rail
Capacity	Very good	Fair	LL Rail
Side Effects	Good	Fair	LL Rail
Passenger Attraction	Very good	Poor	LL Rail
Community:			
Quality of Service	Very good	Fair	LL Rail
System Impact	Good	Fair	LL Rail

Notes: *Including auto and bus feeders.
**Not including cost of automobiles for access.

Performance and Results

The results of these two types of service are drastically different. The rail line, with only 13 stations (7 outlying), attracts 43 percent more passengers than the bus network, which has 26 routes and some 1,500 stopping locations. The Lindenwold Line carries approximately twice as many passengers as NJT into and out of Philadelphia, although the buses attract a larger share of local trips because of their better area coverage.

The PATCO line involved an incomparably higher investment, but it is much more economical to operate. It has low operating costs, and its high level of service enables it to attract more passengers than NJT. As a result, the Lindenwold Line achieves an approximately 44 percent higher operating ratio than NJT, although it charges fares that are between 20 and 30 percent lower.

The direct and indirect impacts of the Lindenwold Line, such as reduction in congestion, increased convenience of travel, attraction of area residents, and impacts on suburban development, are much greater than the impacts of buses. The blending of the buses into the highway network makes their impact much less distinctive and of much lower magnitude. Moreover, the Lindenwold Line has a great potential to support stronger land-use planning and stimulate different urban forms, whereas buses tend merely to follow developments and existing urban form.

CONCLUSIONS: REAL-WORLD EXPERIENCE WITH RAIL AND BUS MODES

This comparison of rail and bus systems that have served the same area for 22 years provides valuable real-world information that should clarify and correct some of the opinions often found in theoretical writings on this topic. A critical review of these writings is presented by Vuchic (*10*).

Basic Features that Attract Passengers

The following conclusions have been drawn about the major features that attract passengers to transit:

- Intensive, high-frequency, high-performance service is vastly superior to extensive, low-quality service, even in low-density suburban areas.
- A distinct line with an infrastructure independent of highway and other traffic provides a permanence and image that strongly attract passengers.
- Flexibility, often claimed as a great advantage of buses, if carried to an extreme is actually detrimental to the passenger-attracting capabilities of a transit system.
- The major service features that attract passengers are high operating speed; high frequency and reliability; and easy,

convenient access by different modes. If these features are provided, certain elements of service, such as the provision of seating, need not be always provided.

- The out-of-pocket cost is more important for passengers than the total cost. They are more sensitive to fares than to such costs as owning an automobile for P&R travel, which may be much higher in the long run than many passengers realize.

Suggested Bus Line Improvements: Service More Similar to Rail

Bus services in southern New Jersey are excessively adjusted to individual user groups; as a result, the routes are complicated and difficult to understand even by regular users. The advantage of buses, which are able to operate on most streets, should not be used to disperse their service and dilute their image. This fact has been proved, for example, in Ottawa, where bus services are much more similar to rail transit service and attract more passengers than most other comparable bus systems.

Possible Rail Line Improvements: Lower Investment for a Larger Network

The PATCO line was designed and built so economically and efficiently that no significant improvements are needed. For transit modes in general, however, certain simplifications of infrastructure and compromises to allow grade crossings (i.e., use of light rail in certain situations) may result in larger networks with better area coverage. In some cases, the downgrading of service through this change is not significant and makes larger rail networks feasible; in others, such as the Lindenwold Line, the quality loss would probably not be offset by the gains from an extended network. The decision on the quality of network, which changes the ratio between investment cost and level of performance, must therefore be based on local conditions.

Correcting Misconceptions about Rail Transit

Various theoretical studies critical of rail transit as a mode have been given considerable publicity in the United States and Great Britain, regardless of their quality and accuracy. Even some government officials and reputable organizations, such as The Urban Land Institute, have made statements to the effect that buses are not only cheaper, but can offer services superior to rail because of their flexibility and ability to serve large, low-density areas (*11*). Rail transit, it is admitted, may be economical and efficient on the existing lines in older cities, but it is said to be expensive and ineffectual for low-density suburbs.

This paper, as well as many earlier studies (*1,3,4,7*), clearly shows that these theoretical studies that make a general criticism of rail transit modes are incorrect. Different modes have different domains of optimal applications. Statements that either rail or bus is better than the other for most applications are inherently wrong. Actually, the two modes are complementary: rail lines usually depend on bus feeders.

In reality, rail transit offers superior service to that of buses in dispersed networks, and it is much more attractive to automobile drivers. With the downgrading of busways into HOV lanes in many U.S. cities, the competitiveness of buses with automobiles has been further eroded.

A second important conclusion is that the large investment rail transit requires is probably the only significant negative aspect of rail transit. If the projected ridership and impacts justify the investment, rail transit can have higher operating ratios than those typical for either older rail or modern bus systems.

Consequently, rail transit can in many cases represent the most effective and, in the long run, most economical transit mode for both high-density cities and low-density suburbs. Its effectiveness consists of strong attraction of automobile passengers, a decrease of traffic and parking pressures in cities, and positive influences on urban form and environment. This conclusion explains why most of the recent construction of rail transit has been taking place in automobile-oriented cities (e.g., Los Angeles, San Diego, Edmonton, Sacramento, San Jose, Calgary, Portland, and San Francisco), which have recognized that highways alone cannot satisfy their needs.

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