Philadelphia Center City Commuter Railroad Connection

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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.

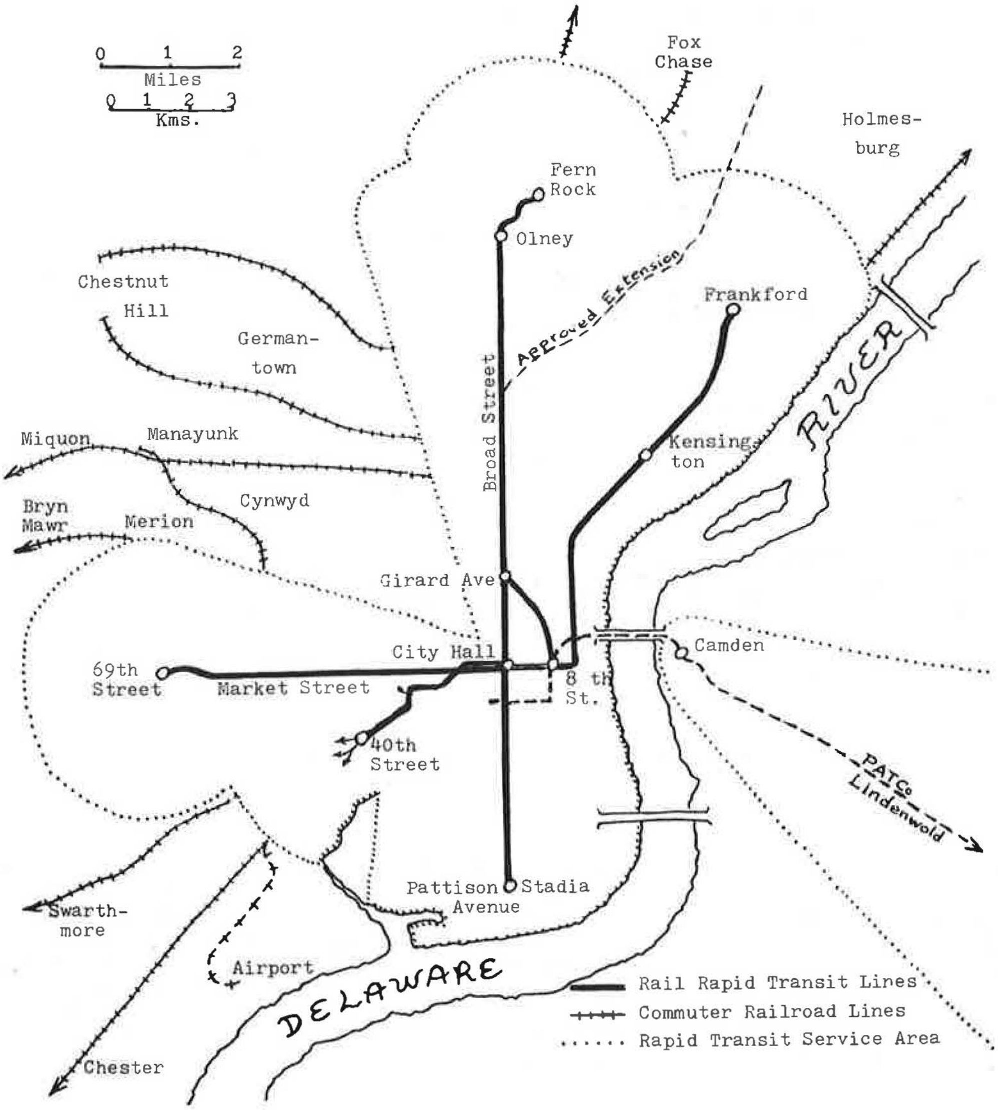
Just as it is infeasible to serve the dispersed suburbs with rapid transit, it is infeasible to serve the highest-density areas with commuter rail. It should be noted that, both in Philadelphia and throughout the country, commuter rail is carrying an increasing percentage of the urban transit work load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

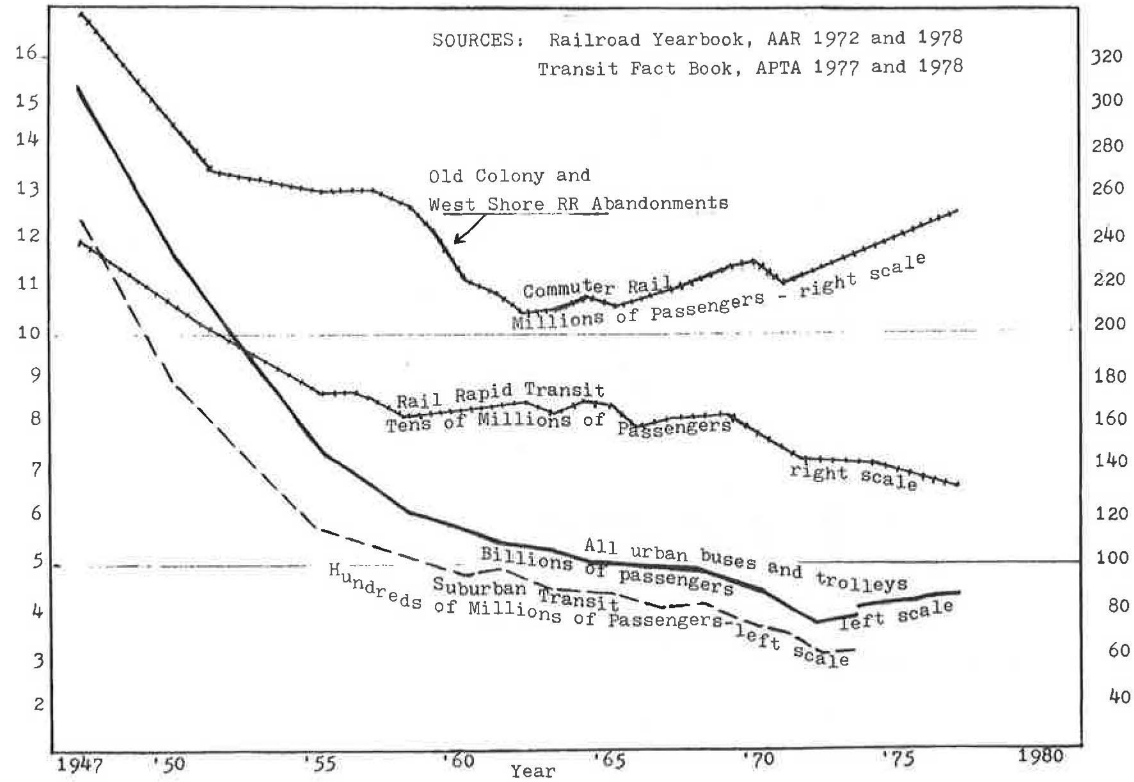
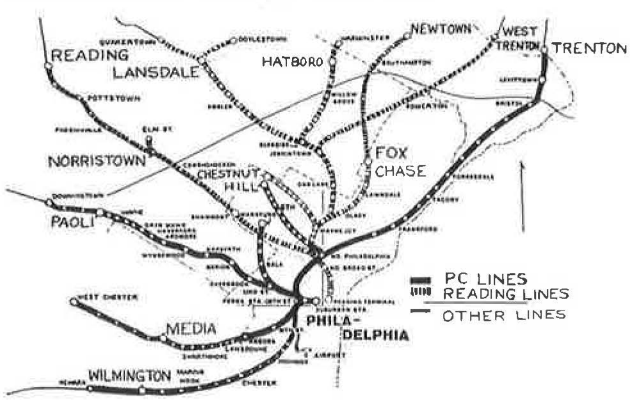


Figure 3. Philadelphia commuter rail system: 1979.



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.

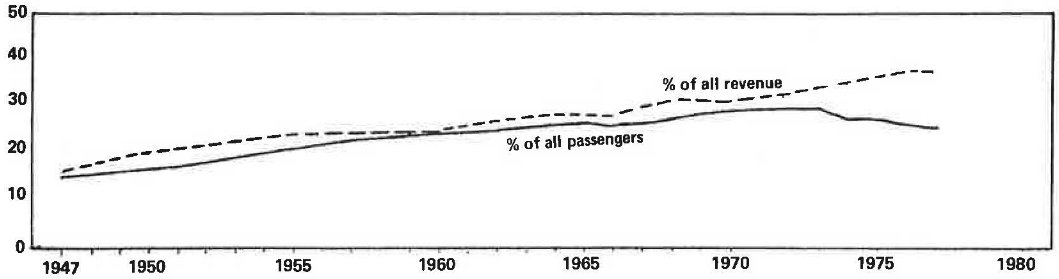


Figure 5. Center City Commuter Railroad Connection: Philadelphia CBD.

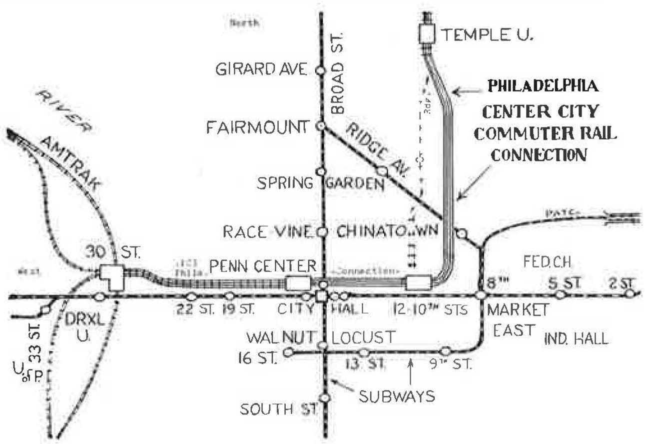


Table 1. Center City average weekday rail-passenger traffic.

Rail Line	Weekday Passengers Penn Center	Market East	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

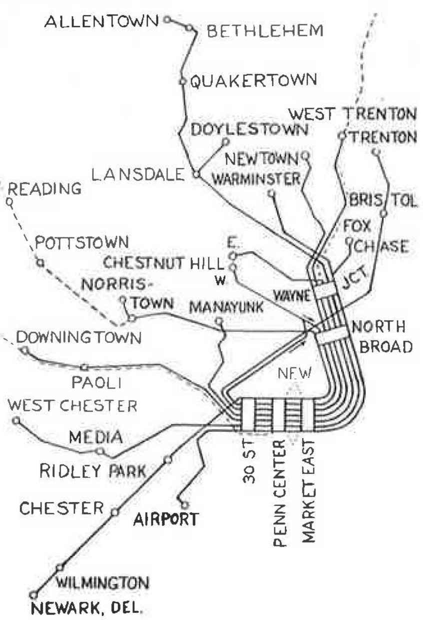
The second economic gain that will result from an integrated commuter rail operation will be revenue increases generated by through-routed-trip time savings and more direct delivery to additional CBD destinations. Modal-split analyses have determined that from 13 000 to 18 000 additional rail trips/weekday 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

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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.