# Application of Transit Operating Cost Models

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A set of cost models that were developed for the Queens Subway Option Study, in which it was necessary to perform a cost buildup analysis, is described. This analysis entailed the comparison of operating costs of five alternatives with varying use of rapid transit, commuter rail, and bus service. Thus it was important for the models to be absolutely, and not just relatively ("rank-wise"), accurate.

BACKGROUND

Cost models were developed for surface transit (bus), rapid transit, and commuter rail operations. The bus cost model is a three-factor cost model based on bus-miles, bus-hours, and peak-period buses. The rapid transit and the commuter rail operating cost models are cost buildup models that separate costs into activity groups with well-defined functions.

The bus, rapid transit, and commuter rail models were developed to evaluate operating costs for five different transportation alternatives with the degree of accuracy that was required for the Queens Subway Options Study. The models can be used to evaluate complete system operating costs. In the Queens Subway Option Study incremental operating costs were evaluated by inputting the incremental value of the required cost parameters. However, these incremental cost parameters were evaluated by calculating the total value of the input parameter for the desired alternative and subtracting from it the present value of that parameter.

The five alternatives investigated in the Queens Subway Options Study are shown in Figure 1 and are briefly described to facilitate discussion of the application of the cost models in specific instances. It should be noted that this paper is intended only to address the structure and application of the cost models using these five alternatives as examples and not in any way to compare the operating costs or other merits of the five alternatives.

Alternative 1--No Additional Construction

This alternative includes only those projects already built or under construction. Included are the 63rd Street subway tunnel from Manhattan to Long Island City in Queens and the Archer Avenue subway in Jamaica. In addition, certain bus routes in Jamacia will be modified to serve the new subway lines.

Alternative 2--Queens Boulevard Line Local Connection

This alternative proposes that the local tracks of the existing Queens Boulevard line be connected to the terminus of the 63rd Street subway in Long Island City. It increases the utilization of the subway system to provide the new service by rerouting current Queens local service to Brooklyn into Manhattan. A number of local trains are added, and local tracks are thus used to their full capacity. Buses are rerouted as in Alternative 1.

Alternative 3--Queens Bypass Express

This alternative proposes that a new two-track subway line be built at grade alongside the Long Island Rail Road (LIRR) main line to connect the 63rd Street subway to the Queens Boulevard express lines in Forest Hills. This service differs from Alternative 2 by enriching the express service in eastern Queens instead of the local service in western Queens. Buses are rerouted as in Alternative 1.

Alternative 4--Subway-LIRR Montauk Transfer

This alternative proposes that the Montauk branch of the LIRR be electrified for commuter rail operation, employ MU cars, and serve eastern and southeastern Queens. The new commuter rail operation would terminate at a new station in Long Island City where passengers would transfer to a subway that connects

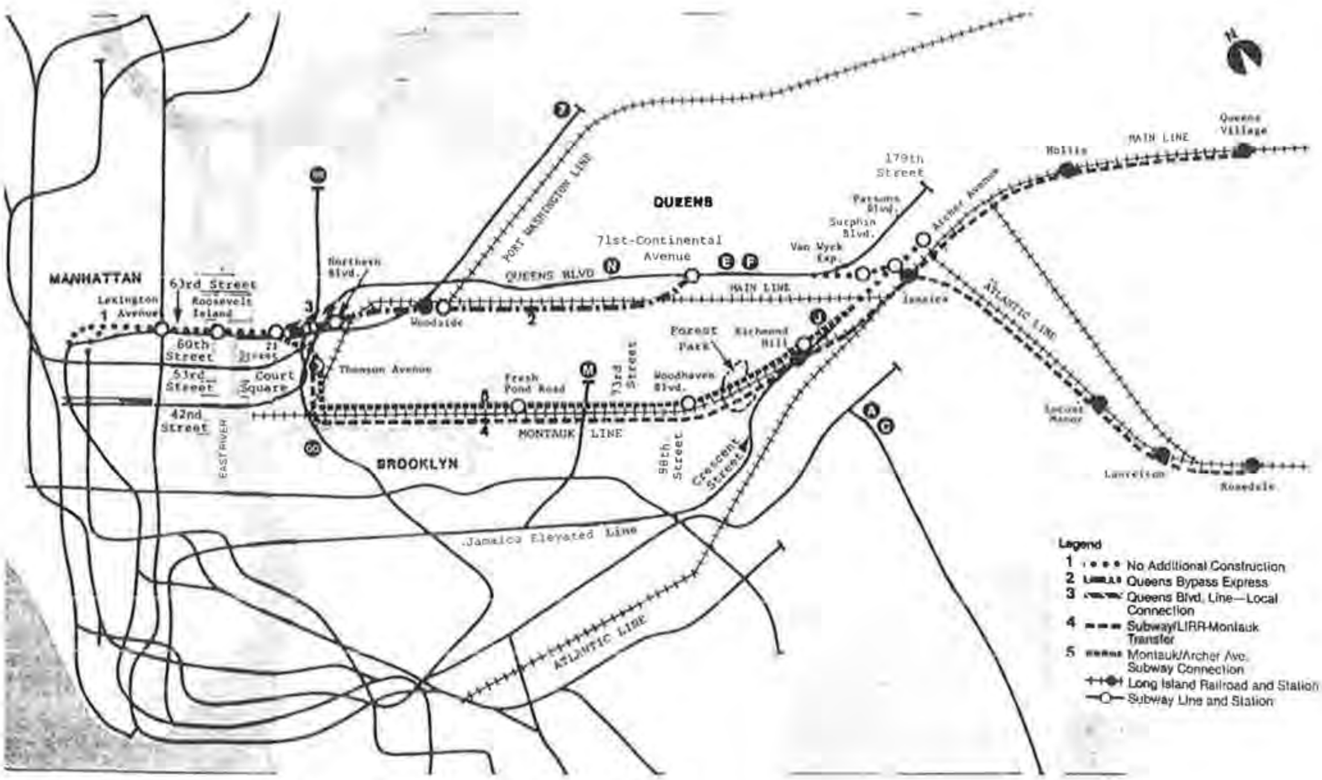


FIGURE 1 Queens Subway Options Study, all alternatives.

to the current terminus of the 63rd Street subway. In addition to the bus routings for Alternative 1, bus service to five LIRR stations would be increased to match the schedule of the proposed commuter rail operation. This alternative would provide new LIRR service to currently underserved areas of southern Queens with a transfer in western Queens to the new 63rd Street subway.

Alternative 5--Montauk-Archer Avenue Subway Connection

This alternative proposes that the LIRR Montauk branch be electrified and converted to subway operation. The new subway would connect the 63rd Street subway to the Archer Avenue subway. A significant portion of the Jamaica elevated line would be demolished. In addition to the bus routings for Alternative 1, several bus services would be expanded to serve the new stations on the Montauk-Archer subway. The operation of the Montauk-Archer subway has a number of cost impacts on the LIRR; these are evaluated using the commuter rail cost model. This alternative provides new service to areas in Queens by converting the Montauk line to subway.

## OPERATING ISSUES

The successful application of the three operating cost models to an actual transit system requires a considerable amount of information about system operations with particular emphasis on limitations and constraints imposed by existing conditions. This was demonstrated in the Queens Subway Options Study in a number of instances related to rail transit. Major operational issues for both rapid transit and commuter rail operations include location of storage yards and train-turning at terminals as well as at intermediate locations. Other issues such as crew assignments for commuter rail operations required a detailed investigation in order to establish appropriate inputs to the associated cost model. Similarly, a detailed study of freight operations was required for a line that would share passenger and freight traffic.

Yarding of trains is a major consideration in any rail transit operation. Ideally, yards should be located at either end of the line to allow put-ins and lay-ups. In the Queens Subway Options Study, four of the five alternatives required new or expanded yard facilities to accommodate the additional train sets required.

In Alternatives 3 and 5 the nearest possible location of the new subway yards was approximately 9 mi from the Queens terminal of each line. Consequently, in these two alternatives, about 20 percent of the incremental car-miles incurred resulted from deadhead moves to and from the yards. These deadhead train moves accounted for about 5 percent of the total incremental operating cost for each alternative--more than $1.5 million per year.

In Alternative 2 storage for an additional 20 subway train sets was required. The most practical alternative was to redesign an existing yard in Brooklyn, which requires relocating certain maintenance-of-way facilities. The proposed storage location is quite removed (about 19 mi) from the Queens terminal of the line; consequently, considerable car mileage is accumulated that could have been avoided had storage facilities in Queens been available.

In Alternative 4 storage facilities were provided for MU train sets at one of the two eastern terminals and at the western terminal. This increased car mileage somewhat.

In both the rapid transit and commuter rail portions of the Queens Subway Option Study, train-turning proved to be of considerable importance in developing operating plans. The resulting operating costs incurred were often quite significant.

In the rapid transit portion of the study, turning capacities were investigated for all major terminals of interest and for several intermediate turning locations, principally in lower Manhattan. For example, the maximum turning capacity at Whitehall Street in lower Manhattan was estimated to be 10 trains per hour due to the crossover configuration of the approach to the station. In two of the alternatives, Whitehall Street appeared to be an ideal terminal in which to turn all new trains originating in Queens. However, because of the limited turning capacity, it was necessary to route trains to Coney Island instead--an additional distance of more than 11 mi to the other end of the line in Brooklyn. This resulted in a considerable increase in operating cost for that particular train service.

Train-turning limitations at certain Queens locations also affected operating plans and hence operating costs. For example, in Alternative 3 it was desired to terminate trains operating on the Queens bypass express at Continential Avenue during off-peak hours instead of continuing to the two terminals in Jamaica. However, the track configuration of the bypass express did not permit direct access to a nearby yard where trains could be easily layed up. Instead trains had to be turned on express tracks nearly a mile away. This train-turning operation was limited to those off-peak periods in which all trains were operating on 10-min headways; otherwise line capacities would have been exceeded. As a consequence, more than 10 percent of the incremental car mileage associated with these services was due to the inability to turn off-peak trains at the desired location.

Train-turning was also an important factor in the operation of the commuter rail service in Alternative 4. Due to track configurations on the branch serving southeastern Queens, trains had to be turned at Valley Stream 2 mi beyond the last station to be served on that line.

## RAPID TRANSIT OPERATING COST MODEL

The rapid transit operating cost model is structured as a cost buildup model that separates operating costs into activity groups that have well-defined functions. Each of these activity groups is then related to one or more physical characteristics of the rapid transit system; for example, propulsion power costs are related to vehicle-miles.

The rapid transit operating cost model consists of 12 activity groups. Six of these activity groups deal with labor costs, five deal with materials and supplies, and one estimates the authority's general and administrative costs with respect to the rapid transit department. The rapid transit operating cost model is given in Table 1. The activity groups are described next.

The labor cost groups have special factors (multipliers) associated with fringe benefits, administrative and support employees, minor direct expenses for materials and supplies, and general and administrative costs.

The authority's general and administrative costs are primarily associated with personnel; therefore the estimating equation is predicated on the total cost for rapid transit.

The direct expense activity costs are major material, supplies, and other costs associated with maintaining vehicles, stations, and right-of-way and with propulsion power and public liability. Because these costs are normally purchases from a vendor, no multiplier factors were used in developing the estimating equations.

These 12 activity groups use seven independent variables: (a) platform hours, (b) towers, (c) ticket booths, (d) stations, (e) miles of running track, (f) active vehicles, and (g) annual car-miles. Table 2 gives a list of the independent variables that are required in each of the 12 activity group costs.

## CALCULATION OF INDEPENDENT VARIABLES FOR RAPID TRANSIT OPERATING COST MODEL

The operating plan of each alternative was analyzed to calculate the seven independent variables of the rapid transit operating cost model. Track-miles, stations, token booths, and towers are generally determined by the physical characteristics of the system and are little influenced by operational considerations. On the other hand, operational considerations have a significant impact on car-miles and platform-hours and, to a lesser extent, on active vehicles.

**TABLE 1 Rapid Transit Operating Cost Model**

| Activity Group | Calculation |
|---|---|
| Vehicle operating labor | [(Platform-hours x Pay-hours/Platform-hour x Operator wages/Hour) = (Towers x Towermen/Tower x Annual salary/Towerman)] x MULT(VOL) |
| Station operating labor | (Ticket booths x Station operating employees/Ticket booth x Annual salary/Employee) x MULT(SOL) |
| Station maintenance labor | (Stations x Maintenance employees/Station x Annual salary/Employee) x MULT(SML) |
| Right-of-way and system maintenance labor[a] | (Miles of running track x Maintenance employees/Mile x Annual salary/Employee) x MULT(ROW) |
| Vehicle maintenance inspection labor[b] | (Active vehicles x Maintenance employees/Vehicle x Annual salary/Employee) x MULT(VMIL) |
| Vehicle maintenance labor[c] | [Annual car-miles (in millions) x Maintenance employees/Million car-miles x Annual salary/Employee] x MULT(VML) |
| Authority general and administrative cost | Sum of labor cost equations x Factor |
| Vehicle maintenance materials and supplies | Car-miles x Cost/Car-mile |
| Station maintenance materials and supplies | Stations x Cost/Station |
| ROW and systems materials and supplies | Miles of running track x Cost/Mile |
| Propulsion energy | Car-miles x Kilowatt-hour/Car-miles x Cost/Kilowatt-hour |
| Public liability | Car-miles x Cost/Car-mile |

Note: MULT (activity group) = Staff burden multiplier for activity group x Fringe benefits multiplier for activity group x Direct expense multiplier for activity group x General and administrative multiplier for the Rapid Transit Department.

[a]Right-of-way and system maintenance labor includes track maintenance and electrical power system maintenance.

[b]Vehicle maintenance inspection labor contains all costs associated with normal vehicle maintenance and inspection duties. It is related to active vehicles, given a consistent inspection per year.

[c]Vehicle maintenance labor contains all costs associated with the repair and maintenance of vehicles. It is related to car-miles, given a repair schedule or need based on usage.

**TABLE 2 Independent Variables for Activity Groups**

| Activity Groups and Independent Variables | Platform-Hours | Towers | Ticket Booths | Stations | Miles of Running Track | Active Vehicles | Annual Car-Miles |
|---|---|---|---|---|---|---|---|
| Vehicle operating labor | x | x | | | | | |
| Station operating labor | | | x | | | | |
| Station maintenance labor | | | | x | | | |
| ROW and system maintenance labor | | | | | x | | |
| Vehicle maintenance inspection labor | | | | | | x | |
| Vehicle maintenance labor | | | | | | | x |
| Authority general and administrative costs | s | s | s | s | s | s | s[a] |
| Vehicle maintenance materials and supplies | | | | | | | x |
| Station maintenance materials and supplies | | | | x | | | |
| ROW and systems materials and supplies | | | | | x | | |
| Propulsion energy | | | | | | | x |
| Public liability | | | | | | | x |

Note: x indicates this independent variable is used for the function; s indicates sum.

[a]Uses sum of labor.

Car-miles and platform-hours are similar input variables and are related by the speed of the train and the consist. The higher the average speed, the higher the ratio of car-miles to platform-hours. For a given consist and average speed, factors that increase (or decrease) one variable will also cause a proportionate increase (or decrease) in the other variable. On the other hand, if an eight-car peak-hour consist is reduced to four cars for off-peak service, an off-peak round trip will require the same number of platform hours but only half as many car-miles as a peak-period round trip.

Active vehicles include the equipment necessary to maintain peak-hour service, including an allowance for spare vehicles. The allowance for spare vehicles is based on data for the particular rail operation being modeled. A spare ratio of 15 percent was used for subway cars and 14 percent for LIRR MU cars.

Operational factors that affect car-miles and platform-hours may have a significant effect on the number of active vehicles--or no effect at all. A simple hypothetical example can illustrate this. Suppose a new peak-period-only service that operates on 10-min headways is to be provided (i.e., six trains

**TABLE 3 Long Island Rail Road 1983 Operating Cost Model**

| Function | Calculation |
|---|---|
| Train and engine service employees | Annual engine service tours/215 available days per engineer + Annual train service tours/212 available days per trainman + 11 trainees |
| Other transportation craft employees | 512.0 + 0.456 x Number of outlying stations |
| Transportation noncraft employees | 0.0805 x (Other transportation craft employees + Train and engine service employees) |
| Transportation labor costs[a] | \$40,570 x Train and engine service employees + \$39,059 x Other transportation/Craft Employees + \$36,104 x Transportation noncraft employees |
| Other transportation costs | \$479,134 + \$83.37 x Annual trains entering Penn Station + \$4,964 x Route-miles + \$6,697 x Outlying stations + \$1,295 x Total transportation employees |
| Energy costs[b] | \$1,103,000 + \$0.1878 x MU car-miles in New York City + \$7,280 x (55 x Million DH car-miles + 135 x Million Locomotive/PU-miles) |
| Maintenance-of-equipment employees | 229.8 + 0.643 x Daily MU requirement + 0.075 x MU fleet size + 7.33 x Million MU car-miles + 0.954 x Annual number of MU cars overhauled |
| Diesel-hauled car employees | 47.5 + 0.6836 x (Daily DHC requirement + Loco/PU daily requirement) + 0.3922 x Daily DHC requirement + 2.82 x Million DH car-miles + 1.76 x Annual number of DH cars overhauled |
| Locomotive employees | 29.6 + 1.329 x Daily locomotive and power unit requirement + 25.3 x Million locomotive unit-miles + 1.4 x (Million MU car-miles + Million DH car miles + Million locomotive/PU-unit miles) |
| Maintenance-of-equipment | |
| Noncraft employees | 0.1234 x (MU employees + DHC employees + Locomotive employees)[c] |
| Labor costs | \$38,517 x (MU employees + DHC employees + Locomotive employees) + \$33,638 x Maintenance of equipment noncraft employees |
| Material costs | \$0.477 x MU car-miles + \$0.465 x DH car-miles + \$0.467 Locomotive unit-miles + \$36,980 x Annual number of MU cars overhauled + \$6,870 x Annual number of DH cars overhauled |
| Other costs | \$2,140,000 + \$527 x MU fleet size + \$446 x (MU fleet size + DHC fleet size) + 2.92 x annual number of cars entering Penn Station + \$0.021 x (MU car-miles + DH car-miles + Locomotive/PU unit-miles) |
| Maintenance-of-way | |
| Craft employees | 300.75 + 2.84 x Annual production-miles + 1.188 x Track-miles + 0.617 x Third-rail-miles[d] |
| Noncraft employees | 81 |
| Labor costs | \$39,602 x Craft employees + \$35,958 x Noncraft employees |
| Material costs | \$221,068 x Production-miles + \$13,743 x Track-miles + \$7,698 x Third-rail-miles + \$988 x Route-miles |
| Other costs | \$9,357 x Track-miles + \$301 + 1.4617 x Annual number of cars entering Penn Station |
| Police | |
| Employees | 200 |
| Labor costs | Employees x 40110 |
| General and administrative costs | 0.2612 x (Transportation labor costs + Maintenance-of-equipment labor costs + maintenance-of-way labor costs + Police labor costs) |

Note: This model was developed by Steve Lawitts of the Long Island Rail Road. It has been calibrated for 1983 costs.

[a]The coefficients in all labor cost equations include base salary plus fringe benefits.

[b]Includes that part of electricity cost incurred only by operations in New York City.

[c]Includes trainees and engineering staff, some of whom are unionized and some of whom are not. They do not receive overtime or night differential pay.

[d]Includes draftsmen and designers, who are unionized and who receive overtime and night differential pay.

**TABLE 4 Independent Variables and Functions**

| Function | Independent variable | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Engine Service Tours (annual) | Train Service Tours (annual) | Trains Entering Penn Station | Cars Entering Penn Station | No. Outlying Stations | Route-Miles | MU Unit-Miles in NYC | Track-Miles | Production-Miles | Third-Rail-Car Miles |
| Train and engine service employees | x | x | | | | | | | | |
| Other transportation craft employees | | | | | x | | | | | |
| Transportation noncraft employees | s | s | | | x | | | | | |
| Transportation labor costs | s | s | | | x | | | | | |
| Other transportation costs | s | s | x | | x | x | | | | |
| Energy costs | | | | | | | x | | | |
| MU employees | | | | | | | | | | |
| Diesel-hauled car employees | | | | | | | | | | |
| Locomotive employees | | | | | | | | | | |
| Maintenance-of-equipment | | | | | | | | | | |
| Noncraft employees | | | | | | | | | | |
| Labor costs | | | | | | | | | | |
| Material costs | | | | | | | | | | |
| Other costs | | | | x | | | | | | |
| Maintenance-of-way | | | | | | | | | | |
| Craft employees | | | | | | | | x | x | x |
| Noncraft employees[a] | | | | | | | | | | |
| Labor costs | | | | | | | | x | x | x |
| Material costs | | | | | | x | | x | x | x |
| Other costs | | | | x | | | | x | | |
| Police | | | | | | | | | | |
| Employees[a] | | | | | | | | | | |
| Labor costs[a] | | | | | | | | | | |
| General and administrative costs | s | s | | | s | s | | s | s | s |

Note: x indicates this independent variable is used for the function; s indicates sum.

[a]Fixed constant.

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per hour operate only during the morning and evening rush hours). Also suppose that the round-trip time is 2 hr and is equal to the duration of each peak period. As a result, all trains make only one round trip in the morning and one in the evening. Thus 12 train sets are required to operate this service. Now suppose that it is desired to operate 12 trains per hour instead of 6. In this instance, twice as much equipment is needed (i.e., 24 train sets) and twice as many car-miles and platform-hours are accumulated. In both cases the equipment has the same utilization factor, namely, each train set makes two round trips per day.

Suppose, on the other hand, that it is desired to operate six trains per hour for a total of 8 hr per day--4 hr during the peak period and 4 hr during the off-peak period. Assuming full-length consists are employed throughout, 8 hr of operation would result in twice as many car-miles and platform-hours as would 4 hr of operation, but no additional equipment would be needed because each train set would make four instead of two round trips each day.

## COMMUTER RAIL OPERATING COST MODEL

The commuter rail model was employed only for Alternatives 4 and 5. In Alternative 4 (Montauk transfer) the model was used to evaluate the operating costs of a new commuter rail operation in Queens. In Alternative 5 (Montauk-Archer) the commuter rail operating costs that were evaluated by the associated cost model resulted from the impact of electrifying the Montauk branch for subway operation.

The commuter rail operating cost model used was developed by the LIRR. The model is fairly detailed and takes into consideration the unique operating characteristics of a commuter railroad operation. As with the previous two models, operating cost has been separated by function. For this model the functions were (a) transportation, (b) maintenance of equipment, (c) maintenance of way, and (d) police.

The calibrated commuter rail operating cost model is given in Table 3. Unlike the rapid transit operating costs, this model contains some constant terms that represent fixed costs of operating the system. For example, the model estimates the number of maintenance-of-way craft employees as a function of production-miles, track-miles, and third-rail-miles plus 300 employees. This is, there are 300 employee positions in the maintenance-of-way section not directly related to the number of track-miles.

The model contains 21 equations that use 20 independent variables. Table 4 gives the independent variables that are required in each of the 21 cost equations.

## CALCULATION OF INDEPENDENT VARIABLES FOR COMMUTER RAIL OPERATING COST MODEL

The independent variables (see Table 4) were evaluated on an incremental basis to develop incremental operating costs for the Montauk transfer alternative. MU car-miles were evaluated for the new commuter rail service in Queens. MU car-miles in New York City account for different electricity rates for New York City and the rest of the system. The value is the same as MU car-miles in this application. A credit for reduced diesel-hauled car-miles and locomotive and power unit miles was calculated for three diesel trains for which service was discontinued on the Montauk branch.

The MU fleet includes new MU cars to operate the proposed service as well as a 14 percent allowance for spare cars, based on the current LIRR spare ratio for MU cars. The estimate for annual number of MU cars overhauled is based on an average percentage of the MU fleet undergoing an annual overhaul. Annual engine and train service tours account for all transportation operating labor. The derivation of these two input parameters is relatively complex and is described in greater detail later. The number of outlying stations is the net total of stations added and deleted from the system. Track-miles represent the total one-way mileage of track, including yards.

**TABLE 4 continued**

| Function | Daily MU Requirement | Daily DHC Requirement | Daily Loco/PU Requirement | MU Fleet Size | DHC Fleet Size | MU Unit-Miles | DHC Unit-Miles | Loco/PU Unit-Miles | MU Overhauls | DHC Overhauls |
|---|---|---|---|---|---|---|---|---|---|---|
| Train and engine service employees | | | | | | | | | | |
| Other transportation craft employees | | | | | | | | | | |
| Transportation noncraft employees | | | | | | | | | | |
| Transportation labor costs | | | | | | | | | | |
| Other transportation costs | | | | | | | | | | |
| Energy costs | | | | | | | x | x | | |
| MU employees | x | | | x | | x | | | x | |
| Diesel-hauled car employees | | x | x | | | | x | | | x |
| Locomotive employees | | | x | | | x | x | x | | |
| Maintenance-of-equipment | | | | | | | | | | |
| Noncraft employees | s | s | s | s | | s | s | | s | s |
| Labor costs | s | s | s | s | | s | s | | s | s |
| Material costs | | | | | | x | x | x | x | x |
| Other costs | | | | x | x | x | x | x | | |
| Maintenance-of-way | | | | | | | | | | |
| Craft employees | | | | | | | | | | |
| Noncraft employees[a] | | | | | | | | | | |
| Labor costs | | | | | | | | | | |
| Material costs | | | | | | | | | | |
| Other costs | | | | | | | | | | |
| Police | | | | | | | | | | |
| Employees[a] | | | | | | | | | | |
| Labor costs[a] | | | | | | | | | | |
| General and administrative costs | s | s | s | s | | s | s | s | s | s |

Note: x indicates this independent variable is used for the function; s indicates sum.

[a]Fixed constant.

Annual production-miles represent the number of miles of track to be renewed each year. At present, 7 percent of all LIRR trackage is renewed each year. Third-rail-miles include those track-miles that are electrified.

Four of the 20 independent variables are most directly affected by operational considerations: MU car-miles, MU fleet size, annual engine service tours, and annual train service tours. The factors that contribute to these four inputs include

* Peak-period headways,
* Amount of off-peak service provided,
* Train-turning considerations at terminals,
* Midnight and midday train storage locations, and
* Peak and off-peak consists.

The calculation of transportation labor using the commuter rail cost model required a relatively sophisticated estimate of the number of employee service tours required to operate the proposed service. The model has two transportation labor inputs, engine service tours and train service tours. A service tour is defined as a day's work for one person as part of a train crew. Engine service tours include engineers only. Train service tours include all other personnel including the conductor and an assistant conductor (both of whom are required on every train), ticket collectors, and yards crews required to split train consists for off-peak service.

Service tours were estimated employing separate calculations for the basic train crew (engineer, conductor, and assistant conductor) and ticket collectors, and an estimate was also made of the number of yard crews required.

Annual yard crew service tours required to split eight-car weekday peak-period train sets into two four-car train sets for off-peak service are equal to four crewmen times 52 weeks per year times five weekdays per week.

As illustrated by the previous discussion, the calculation of certain inputs to the commuter rail cost model requires keen insight into the operation of the rail system.

Certain inputs to the rail cost model arise, at least in part, from situations that do not directly contribute to the operation of commuter rail or rapid transit trains. It was proposed that the Montauk branch of the LIRR be electrified and used for commuter rail operation in Alternative 4 and for rapid transit operation in Alternative 5. The feasibility of these two alternatives was related to the ability of the LIRR to maintain reasonable service to freight customers on the line without interfering with passenger operations. As a consequence various improvements to the right-of-way were required. These increase the "track-miles" input to the commuter rail cost model.

## SURFACE TRANSIT OPERATING COST MODEL

The surface transit operating cost model was structured in a manner similar to a model developed in 1979 for the New York Metropolitan Transportation Authority Management Study. Budget items were allocated to three physical characteristics of the surface transit system: bus-miles, bus-hours, and peak-period buses. The resulting costs for each physical characteristic were then divided by the value of these characteristics, for 1982-1983, to obtain a unit cost per physical characteristic. In general, buses can be costed at the margin; an increase in service requires additional buses and drivers. This method applies as long as the increased service does not require major capital expenditures for new maintenance facilities. This three-factor model is a standard methodology for developing a surface transit operating cost model. The model structure can be conceived of as a linear equation of the form:

Operating cost = Cost per bus mile x Bus miles + Cost per bus-hour x Bus-hours + Cost per peak-period bus x Number of peak-period buses.

The bus model requires only three input parameters: bus-miles, bus-hours, and peak-period buses. As is the case for the rapid transit cost model, bus-miles and bus-hours are related by the average speed of the bus.

Bus routes were altered and service was expanded where necessary to provide feeder bus service to subway stations in each of the five alternatives and to commuter rail stations in Alternative 4. Scheduling of buses was coordinated with rail schedules. In addition, some bus routes were increased in length or new services were created to provide access to these rail stations.