1. What are the intended purposes of these performance measures?
2. What are the specific objectives for transit service?
3. Is there a useful financial, planning, and operating data base available? and
4. Are the funding sources sufficiently predictable that it is realistic to attempt to meet the standards?

The experience of this study is that the value of having indicators and standards is directly related to the degree of positive response to these questions. Without some answers to the questions developed before or during a study, performance measures are surely useless.

The final conclusion is that it is preferable for the development of indicators and standards to be undertaken at the local level, ideally beginning with transit management. The DART study was funded by the local MPO (WILMAPCO), with the cooperation of DART and close coordination with the Delaware Department of Transportation. The local initiative approach has the advantage of being more sensitive to local objectives and concerns, more precise, and more useful as a management tool than are state or federally mandated evaluations. Statewide programs, by definition, are authorized by state legislatures for the primary purpose of funding allocation. Although statewide evaluations may serve this function admirably, they are not generally as helpful to the individual systems.

ACKNOWLEDGMENT

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Diagnostic Tools in Transit Management

Subhash R. Mundle and Walter Cherwony

Historically, transit management had to rely on a technique known as peer-group comparison to identify strengths and weaknesses in the performance of their system. In this technique, performance indicators for the system under study are compared with the average performance of systems that have similar characteristics. This method, though useful, is deficient in that it does not totally reflect the differences in operating characteristics or environment among transit properties. This paper presents a diagnostic tool for comparing performance among transit systems by suggesting a method to eliminate deficiencies in the traditional approach. The paper suggests that combined uncontrolled and controlled comparisons be used to identify relative strengths and weaknesses in performance. The uncontrolled comparison is the traditional approach in which system performance is compared with average performance of the peer systems. The controlled comparison is performed by comparing the actual performance with the expected performance. The expected performance is calculated from models that can be developed from the experience of the peer systems. This paper presents a case study in which uncontrolled and controlled comparison concepts were used to identify strengths and weaknesses of 11 bus depots in the New York City Transit Authority. The paper presents 10 transportation and maintenance performance indicator models that were used to calculate the expected depot performance. The models were developed through stepwise multiple regression analysis of the New York City Transit Authority's actual operating statistics for fiscal year 1977. The paper also discusses how the uncontrolled and controlled comparisons were subsequently used to set priorities among depots for remedial action. The application of the performance comparison technique discussed in this paper to smaller systems would require comparison of the system's performance with that of other similar transit properties.

The limited availability of public funds to underwrite transit deficits and the increasing gap between operating cost and passenger revenue have caused transit managements throughout the nation to strive for improvements in transit system efficiency, effectiveness, and productivity. To accomplish this objective, a two-step process is often employed by transit managers: (a) the identification of problem areas and (b) the development of an action plan to remedy these deficiencies. In view of the limited time and resources available to transit managers, the first step is of utmost importance if efforts are to be focused on problem areas of highest priority. For this reason, there is a need for simple, easy-to-use diagnostic tools to quickly pinpoint transit deficiencies.

The traditional approach to the assessment of transit performance is to compare the performance of a transit system under study with that of transit properties that have similar characteristics. Typically, this peer group comparison is carried out for a variety of performance indicators in which the results of the system under study are contrasted with the average for the peer group. This method is helpful in providing an analytical framework; however, it is deficient in that it does not totally reflect the difference in operating characteristics or environment among transit properties. In essence, this simple comparison technique is uncontrolled since it does not account for inherent differences among systems.

To remedy this situation, a supplemental diagnostic tool is proposed in which the performance of a transit system is measured not only in absolute terms against a peer-group average but also in relative terms with respect to where the system performance should be, given its operating environment. This latter comparison technique is termed a controlled comparison since it attempts to reflect inherent differences among transit properties.

This paper presents a case study of this diagnostic tool applied to the bus operations of the New York City Transit Authority (NYCTA) as part of an overall organization and management study of the entire Metropolitan Transit Authority (MTA). The analysis was performed for 11 depots and 10 performance indicators to identify depots that are deficient in performance and the nature of those problems. Although the New York situation is unique in that the system is sufficiently large that comparisons can be made among depots, the approach is readily applicable to smaller transit properties where the comparison is made with peer-group systems.

CONCEPT DEVELOPMENT

Traditionally, transit system performance has been assessed by using a simple peer-group comparison technique. A variety of indicators are specified to measure various apects of transit performance. Peer-group systems are selected on the basis of similarities among the system under study and the peer-group properties in terms of factors such as fleet size, geographical region, and demographic characteristics of service territory. In the New York City case study, the peer group is merely the 11 depots that constitute NYCTA bus operations. As depicted in Figure 1, the comparison is made between each depot's performance relative to the system or peer-group average. Depot results above the system average would suggest superior performance and results below the average would indicate a deficiency. The problem with this simplified comparison technique is that it does not account for differences in operating characteristics and environments among the depots. For example, a depot that serves suburban Staten Island might exhibit superior fuel economy results, but a Manhattan depot that serves a densely developed portion of New York City might score well below the system average. However, these results might be misleading because they would not reflect the impact of bus operating speed. Thus, the Manhattan depot might be performing better than could be reasonably expected and the Staten Island depot could be performing worse than expected. To rectify this situation, the peer-group comparison is expanded to include a comparison of actual performance relative to expected performance (i.e., controlled comparison).

As shown in Figure 2, the reference line for this comparison is a 45° line rather than a horizontal line, as in the uncontrolled comparison. The actual performance would be the same as that used in the uncontrolled comparison; however, the expected value would be determined from regression analysis of the peer-group depots. The disadvantage of using only a controlled comparison is that it does not relate performance relative to the system. For example, a depot that is worse than expected but better than the average would not be considered a priority location for remedial action, although performance should be improved.

Since each comparison technique provides only part of the information needed for a diagnostic tool, system performance should be assessed by both methods. By combining both procedures, each depot's performance can be categorized into four possible outcomes, as depicted in Figures 3 and 4. The implications of each of the four categories of results are as follows:

1. Better than average and better than expected—a depot that has better performance than the systemwide average as well as actual performance better than expected; the two comparisons are compatible and suggest superior performance;
2. Better than average but worse than expected—a depot that has better performance than the systemwide average but the actual value is less than expected; these results suggest good performance with room for improvement;
3. Worse than average but better than expected—a depot that performs below the systemwide average but better than expected; these results of the controlled comparison suggest satisfactory performance in the face of difficulty; and
4. Worse than average and worse than expected—a depot that scores poorly both in terms of systemwide average and expected value; these results suggest poor performance and the need for further analysis and improvement.

Placement of each of the 11 NYCTA depots in one of these four categories results in the identification of depots that require remedial action for each indicator. By quantifying the results of both comparison techniques, the priority order for remedial action of the depots can be set in order to attain maximum benefits with limited financial resources.

METHODOLOGY

The application of the conceptual framework discussed above requires development of performance indicator statistics for the uncontrolled comparison and the development of performance indicator models so that expected performance can be calculated for the controlled comparison. (These models were designed for U.S. customary units only; therefore, values are not given in SI units.) The first step was the development of a number of transportation and maintenance performance indicators for NYCTA depots that were developed from available operating statistics for fiscal year 1977.

As shown below, 19 operating statistics were considered in the analysis:

1. Operating speed,
2. Passengers per bus mile,
3. Passengers per bus hour,
4. Annual passengers per operator,
5. Operators per bus,
6. Annual bus hours per operator,
7. Operator pay hours per bus hour,
8. Annual bus miles per operator,
9. Annual miles per bus,
10. Ratio of peak bus requirements to base bus requirements,

Figure 1. Uncontrolled comparison.

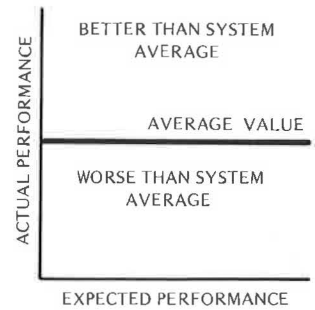
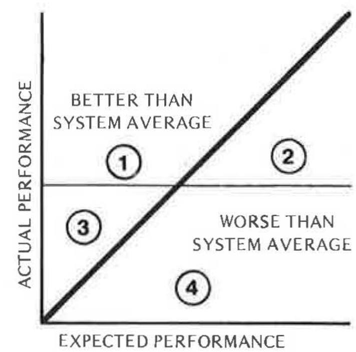


Figure 2. Controlled comparison.

Figure 3. Combined comparison.



11. Average fleet age,
12. Spares ratio,
13. Buses per mechanic,
14. Annual bus miles per mechanic,
15. Annual bus hours per mechanic,
16. Bus miles per quart of oil consumed,
17. Bus miles per gallon of fuel consumed,
18. Bus miles per maintenance-related road call, and
19. Facility age.

However, only 10 performance measure were used in the analysis. As shown below, five indicators each were selected to assess transportation and maintenance performance:

Transportation Indicators	Maintenance Indicators
Operating speed	Buses per mechanic
Operators per bus	Annual bus miles per mechanic
Operator pay hours per bus hour	Bus miles per quart of oil consumed
Annual bus miles per operator	Bus miles per gallon of fuel consumed
Annual miles per bus	Bus miles per maintenance-related road call

In the next step, stepwise linear multiple regression analysis was used to examine the relationship between each performance indicator and those factors or variables that influence it. The regression analysis procedure may be visualized by examining the relation between operating speed and passengers per bus mile, as shown in Figure 5. The scatter of points for each operating depot indicates that a perfect relationship between the two variables does not exist. However, a straight-line graph can be found that best fits the data points. Figure 5 indicates the line of best fit for the NYCTA depots. It is obvious from this example that only one variable is necessary to describe operating speed. In the case of a more complex relationship, more than a single factor may have a role in the determination of the performance indicator. For example, the formula that defines buses per mechanic for the depots relies on both the ratio of peak to base bus requirements and average fleet age.

In selecting a final set of relationships for each of the 10 transportation and maintenance performance indicators listed above, the following guidelines were established:

1. All variables can be easily obtained from NYCTA's normal data collection procedures,
2. Equations should be relatively simple to apply in terms of included variables,
3. Formulas should be logical both in terms of the sign of each coefficient and the variables included, and

Figure 4. Possible performance results.

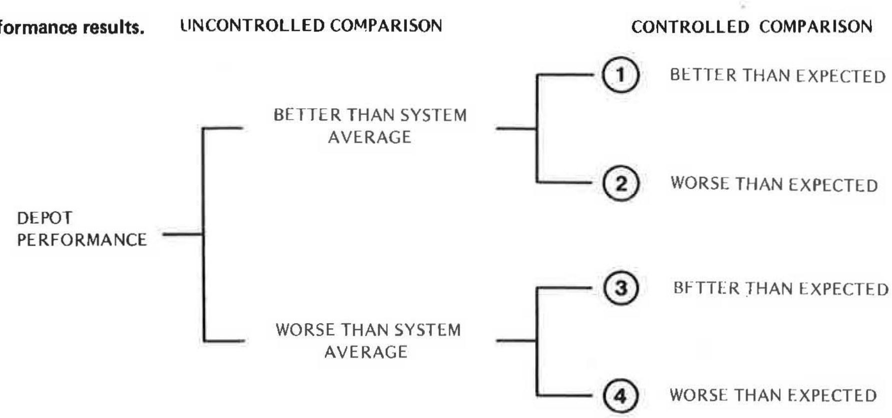
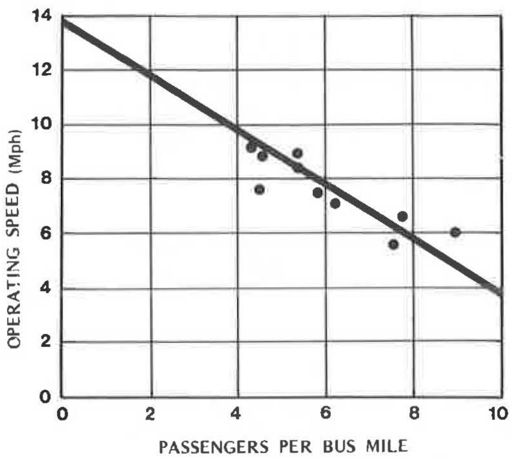


Figure 5. Relationship between operating speed and passengers per bus mile.



4. Relationships quantified should represent a reasonable fit of the data.

Several iterations of the statistical analysis were performed to arrive at the relationships that achieved the greatest satisfaction of the items cited above. It is recognized that numerous diverse factors influence the performance indicators and that quantification of formulas with only one or two explanatory variables represents a simplification. Further, some potential explanatory variables do not lend themselves to mathematical quantification.

As a result of the statistical analysis, mathematical models that describe the relationships for 10 performance indicators were quantified. The models developed provide a reasonable means of predicting expected performance, while making due allowance for the differences in depot operating conditions. These relationships, although not perfect, are relatively easy to derive and can be used on a continuing basis to monitor changes in the level of performance for each measure. The following formulas were used in the controlled peer-group comparisons to predict expected values of the performance indicators.

Transportation Indicators

The formula for operating speed employs only a single explanatory variable. The inverse relationship between operating speed and passengers per mile is obvious, since passenger use, which measures patron boardings and alightings, influences the number of stops.

$$\text{Operating speed} = 13.829 - 1.007 \text{ passengers/bus mile} \quad (1)$$

Two explanatory variables are required to describe operators per bus, which is inversely proportional to the ratio of peak/base bus requirements and directly proportional to miles per bus. As the peaking characteristics of the system increase, the number of drivers per bus decreases and approaches one. Conversely, a system that exhibits a uniform demand throughout the day would enable each bus to be driven by more than a single driver. As the miles per bus increase, the number of drivers per bus also increases; that is, greater use of capital resources causes the need for more drivers. Logically, the more miles that a system operates, which in part is a function of speed, the greater the number of operators needed to provide service.

$$\text{Operators per bus} = 2.149 - 0.357 \text{ ratio of peak bus requirements to base bus requirements} + 0.242 \times 10^{-4} \text{ annual miles/bus} \quad (2)$$

The NYCTA formula relates operator pay hours per bus hour to a single variable—peak-to-base bus ratio. This relationship reflects both the diseconomies associated with establishing the labor requirements based on the peak demand requirement as well as the restrictions and penalties established in the collective bargaining agreement (e.g., spread time, guaranteed time, and minimum straight runs).

$$\text{Operator pay hours per bus hour} = 1.466 + 0.074 \text{ ratio of peak bus requirements to base bus requirements} \quad (3)$$

The number of miles each operator can drive annually is a direct function of the speed at which the bus travels. Higher speeds produce greater mileage statistics; lower speeds translate into fewer miles. In part, this relationship reflects the desire by transit management to provide the same number of hours to each driver to the maximum extent possible.

$$\text{Annual bus miles per operator} = 1289.105 + 1481.040 \text{ operating speed} \quad (4)$$

The statistical analysis for annual miles per bus suggested that two explanatory variables are appropriate. The first, peak/base ratio, is inversely related to the miles per bus. Obviously, with more buses in service for only a limited time period (morning and evening rush hours), the buses accumulate fewer miles. The other variable that influences the number of miles per bus is operating speed. Not surprisingly, higher speeds translate into more miles.

$$\text{Annual miles per bus} = 13\,094.820 - 5876.167 \text{ ratio of peak bus requirements to base bus requirements} + 3187.265 \text{ operating speed} \quad (5)$$

Maintenance Indicators

The NYCTA formula for buses per mechanic has as independent variables both peak and base bus requirements and average fleet age. Because maintenance activities are a function of the number of buses as well as their utilization, the buses per mechanic are directly proportional to the ratio of peak to base requirements. On the other hand, average fleet age is inversely proportional to this performance indicator. Older buses, which are more prone to mechanical failures, require more maintenance employees. Conversely, newer coaches, which should experience fewer mechanical problems, reduce the number of mechanics.

$$\text{Buses per mechanic} = 3.154 + 0.168 \text{ ratio of peak bus requirements to base bus requirements} - 0.094 \text{ average fleet age} \quad (6)$$

The formula to describe annual bus miles per mechanic consists of operating speed and average fleet age.

$$\text{Annual bus miles per mechanic} = 121\,882.700 + 5602.496 \text{ operating speed} - 9490.317 \text{ average fleet age} \quad (7)$$

Oil consumption is inversely proportional to average fleet age in that older buses require more oil per mile.

$$\text{Bus miles per quart of oil consumed} = 202.707 - 11.441 \text{ average fleet age} \quad (8)$$

The NYCTA formula for bus miles per gallon of fuel consumed consists of a single independent variable—operating speed. Experience with most vehicles indicates that higher speeds cause greater fuel economy. Further, higher speeds imply less stop-and-go operation and a reduction in idling time.

$$\text{Bus miles per gallon of fuel consumed} = 1.729 + 0.208 \text{ operating speed} \quad (9)$$

Two variables were included in the equation for bus miles per maintenance-related road call—average fleet age and buses per mechanic. Frequency of breakdowns is inversely proportional to vehicle age, which is logical because older buses are more prone to failure. The model also includes the number of buses per mechanic. As fewer mechanics are available to perform maintenance duties, the miles per breakdown increase. Conversely, fewer buses per mechanic translates into an improved road-call experience.

$$\text{Bus miles per maintenance-related road call} = 7047.614 - 301.010 \text{ average fleet age} - 895.973 \text{ buses per mechanic} \quad (10)$$

The 10 performance indicators and relationships listed above were used in the controlled and uncontrolled comparison of NYCTA depots. For the controlled comparison, expected depot performance is calculated by substituting appropriate values of independent variables in the models discussed. For example, expected depot operating speed is calculated by substituting the passengers per mile statistic for that depot in the operating speed model.

DISCUSSION OF THE RESULTS

In the New York MTA management study, performance of the NYCTA bus depots was evaluated by using the uncontrolled, controlled, and the combined comparisons for each of the 10 indicators discussed. Performance indicators simply highlight the strengths and weaknesses of the operation. Once the weaknesses are identified, steps can be taken to determine the causes and to remedy the deficiencies. In the interest of brevity, the discussion of only one performance indicator—operating speed—is presented here to illustrate the usefulness of uncontrolled and controlled comparisons, followed by the priority order of depots for remedial action (1).

The uncontrolled and controlled comparisons of depot operating speed are illustrated in Figures 6, 7, and 8. From the uncontrolled comparison, in which depot operating speed is compared with the system average (Figure 6), we see that the Castleton Avenue Depot exhibits the highest operating speed and that the 126 th Street Depot exhibits the lowest. This is not surprising since Castleton Depot provides suburban service on Staten Island and 126 th Street Depot operates mostly in Manhattan. The controlled comparison, in which the actual depot operating speed is compared with its expected value (Figure 7), indicates that the 126 th Street Depot exhibits much better actual performance than its expected value, whereas the Crosstown Depot exhibits far worse actual performance than its expected value. The uncontrolled and controlled comparisons by themselves do not indicate those depots that need remedial action.

The combined comparison (presented in Figure 8) indicates the depots that exhibit similar operating speed performance. Those depots that indicate actual performance below system average (as well as below their expected values) obviously warrant further investigation for remedial action. From Figure 8, it can be observed that, even though the operating speed at the 126 th Street Depot is below the system average, the comparison with its expected value indicates a satisfactory performance. Several NYCTA depots, such as Crosstown, East New York, Fifth Avenue, and Freshpond, indicate performance below system average as well as below their expected values. These depots evidently constitute a peer group for improvement in their operating speed performance.

The comparisons, similar to the ones discussed above, were prepared for each of the five transportation and maintenance indicators. The uncontrolled and controlled comparisons were then used to establish management priority to remedy transportation and maintenance deficiencies in NYCTA depots. The priority of depots is determined by ranking the uncontrolled and controlled performance results. The composite uncontrolled ranking for transportation and maintenance functions is prepared in two steps. In the first step, depots for each of the five transportation and maintenance indicators are ranked in a straight ordinal fashion from 1 to 11, where 1 represents the best actual performance and 11 represents the worst actual performance. In the second step, the cumulative score for the depots is again ranked from 1 to 11, where 1 represents the depot that has the least cumulative score for five transportation or maintenance indicators and 11 represents the depot that has the highest cumulative score. The uncontrolled rankings of depots for transportation and maintenance functions are given in Table 1.

The controlled ranking of depots is performed in two steps, similar to the uncontrolled ranking. However, in the controlled ranking, the depots are ranked based on the percentage difference between actual and expected performance (i.e., 1 = the depot that exhibits the highest percent better performance and 11 = the depot that exhibits the highest percent worse performance). The controlled rankings of depots are also shown in Table 1. The rankings shown in this table were used to establish management's priorities for implementing remedial steps at the depots. From the priority scheme given below, it is evident that the comparison of uncontrolled and controlled ranking was helpful in identifying performance deficiencies that would otherwise have gone unnoticed.

Management Priority	Transportation Performance	Maintenance Performance
Top	East New York	Jamaica
	126 th Street	East New York
	Crosstown	126 th Street
	Castleton	Castleton
Second	Fifth Avenue	Fifth Avenue
	Jamaica	Crosstown
	Freshpond	Ulmer Park
Third	Flushing	Queens Village
	Queens Village	Flatbush
	Flatbush	Freshpond
	Ulmer Park	Flushing

For example, under uncontrolled comparison, Castleton Depot ranked on top of all the other depots in transportation and maintenance functions, which indicates superior performance. However, the controlled ranking indicated that there was significant room for improving performance at this depot. Consequently, Castleton Depot was assigned top priority for remedial action. Therefore, both uncontrolled and controlled comparisons are needed to correctly identify deficiencies that are not evident from either of the methods alone. It should be pointed out that the comparison technique and ranking scheme discussed here can also be used to determine the priority of depots for individual performance measures.

Figure 6. Uncontrolled comparison of depot operating speed—actual performance versus system average.

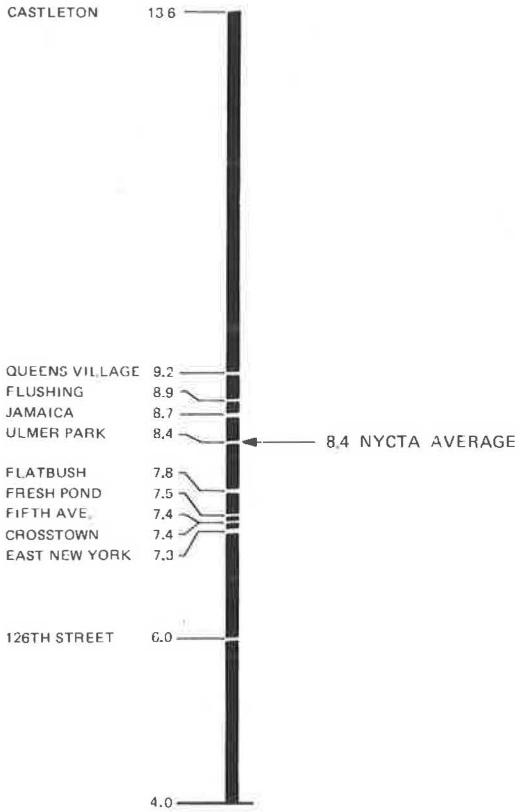
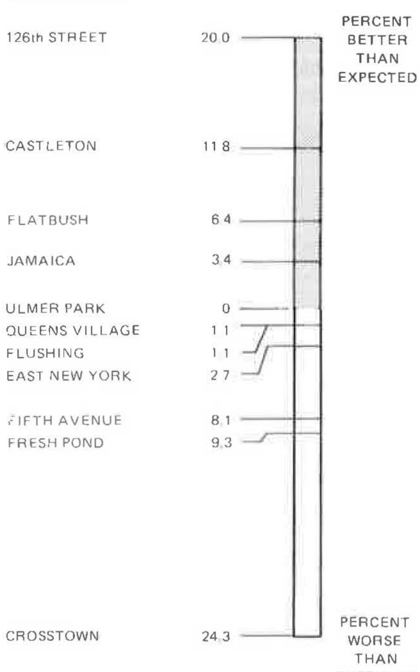


Figure 7. Controlled comparison of depot operating speed—actual versus expected performance.



CONCLUSIONS

The methodology used to compare transportation and maintenance performance of NYCTA depots allows comparison of each depot performance with the system average, as well as with its expected value. Uncontrolled and controlled comparisons provide a useful technique because it not only takes into consideration the interdependency between different indicators but makes an allowance for unique operating characteristics of each depot.

This methodology can be easily adapted to compare performance of depots in other larger transit systems that operate out of multiple operating facilities. Of greater significance is that the technique can also be used to compare performance of one system with the performance of peer systems to identify deficiencies.

The use of only a single comparison technique (uncontrolled or controlled) does not provide sufficient information to diagnose problem areas and to develop a program of priority remedial action; instead, both comparison procedures must be employed. The suggested

Figure 8. Combined comparison of depot operating speed.

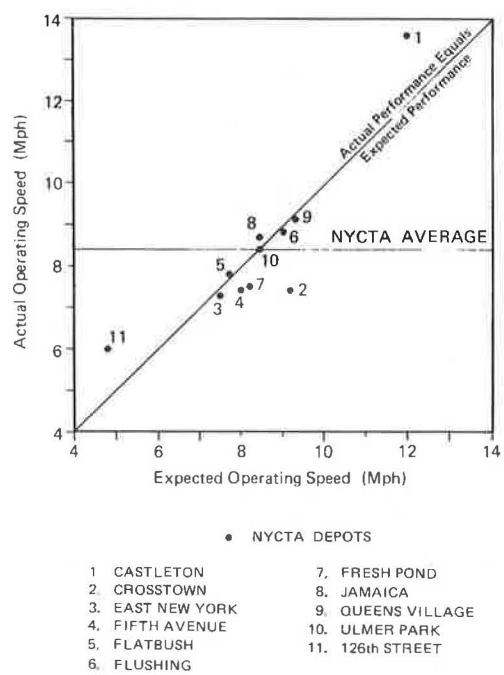


Table 1. Depot ranking for transportation and maintenance performance.

NYCTA Depot	Transportation Performance Ranking		Maintenance Performance Ranking	
	Uncontrolled	Controlled	Uncontrolled	Controlled
Castleton	1	8	1	8
Crosstown	8	11	9	6
East New York	10	10	8	10
Fifth Avenue	9	7	4	7
Flatbush	4	2	2	3
Flushing	5	4	3	1
Freshpond	6	5	6	2
Jamaica	6	6	10	11
Queens Village	3	3	7	4
Ulmer Park	2	1	5	5
126th Street	11	9	11	9

diagnostic tool in this paper is easy to apply and should be used by transit managers on an ongoing, continuous basis to monitor and improve performance.

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Portfolio Model of Resource Allocation for the Transit Firm

David C. Prosperi

An agency resource-allocation model is presented that allows a fuller understanding of performance by linking aggregate performance indicators with diaggregated measures of route-level activity. The evaluative framework is based on the portfolio-choice model of financial management. In this model, aggregate return and risk parameters are found by examining the resource-allocation pattern and ridership levels for individual routes. Although this is primarily an economic utility-maximizing approach, the model parameters were calculated for two time periods and compared in an evaluation of resource reallocation. Before and after levels of service and ridership counts for 41 routes operated by the San Diego Transit Corporation provide the inputs to the modeling effort. Results show that the average return increased with minimal risk impacts in the post-reallocation period, indicating a better resource-allocation package. The relationship between resource allocation and the aggregated average return is thus made explicit and the change in aggregate indicators viewed directly as a function of management and operational considerations at the route level. Finally, the model or method of analysis is evaluated in terms of both its conceptual and measurement procedures.

An evaluative framework for overall transit performance is presented that employs the concepts of resource allocation and economic returns for individual routes. Prior conceptualizations and analyses of transit performance have focused on aggregate measures of inputs, produced outputs, and consumed outputs (1). Route-level analysis of performance is a relatively new phenomenon and critical evaluation of route-level activity is a young enterprise. Route-level demand models have appeared only in the past few years (2, 3) and route-level performance evaluations are still in the stage of ad hoc development (4-6). The purpose of this paper is to formalize and demonstrate an internal resource-allocation model that allows fuller understanding of performance by linking aggregate systemwide performance indicators with disaggregated measures of route-level activity.

The framework is based on the portfolio-choice model of financial management. A portfolio is a collection of activities to which resources can be allocated. The portfolio-selection probelm is to choose investment levels for individual activities so as to maximize a utility function defined over both the expected value of the collected returns of individual activities and the total risk associated with achieving those returns. Thus, the approach allows the derivation of an aggregate systemwide indicator of performance based on an analysis of route-level activity. In the transferral of the model from financial management to an evaluative tool for transit managers, investments are resources assigned to routes, individual activity returns are measures of the patronage of transit routes, the expected value of the portfolio is a weighted average of route investment and return levels, and risk is a measure of the variation in the mean expected return.

TRANSIT PERFORMANCE: ORGANIZATIONAL AND ROUTE ANALYSIS

Transit performance is becoming synonomous with the terms efficiency and effectiveness. In a recent paper, Fielding and others identified nine preliminary performance indicators that focus on these twin evaluative criteria (1). Sticking with standard definitions, efficiency is the ratio between produced output and the amounts of input required to produce them. Effectiveness is the degree to which outputs are consumed or used and a relative measure of output quality. Cost or resource effectiveness is a composite measure and is defined as the ratio of consumed outputs to costs or input magnitudes. As such, this last performance concept serves as an overall indicator of the performance of the entire service provision process, including both the production and the consumption of services.

Fielding, Glauthier, and Lave suggest three general areas of use for their set of performance indicators. They are as follows:

1. Management uses, including the identification of activities within a system in which achieved indicator values are above or below some norm, the comparison of activities of one's own agency against indicator values achieved by similar properties, internal monitoring of production processes, and the stimulation of discussion among transit operators and key personnel;
2. Evaluation of suborganization performance, including the development of objectives and auditing procedures for improvement of activities, route evaluation, and the facilitation of labor negotiations; and
3. Inputs into public policy, by focusing discussion on a common set of issues and criteria.

Although these are all universally considered as legitimate uses of performance measurements and evaluation, specific procedures to accomplish such objectives have yet to be developed at a generalized and transferable level.

Two broad approaches to route-level performance