TRANSPORTATION RESEARCH RECORD 994

Recent Advances in Bus Transit Operations Planning

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1984

Transportation Research Record 994
Price $10.80
Editor: Elizabeth W. Kaplan
Compositor: Harlow A. Bickford
Layout: Theresa L. Johnson

mode
2 public transit

subject areas
11 administration
12 planning
13 forecasting
54 operations and traffic control

Transportation Research Board publications are available by ordering directly from TRB. They may also be obtained on a regular basis through organizational or individual affiliation with TRB; affiliates or library subscribers are eligible for substantial discounts. For further information, write to the Transportation Research Board, National Research Council, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

Printed in the United States of America

Library of Congress Cataloging in Publication Data
National Research Council. Transportation Research Board.
Recent advances in bus transit operations planning.

(Transportation research record; 994)
1. Bus lines–United States–Congresses. I. National Research Council (U.S.). Transportation Research Board. II. Series.
TE7.H5 no. 994 380.5 s 85-8832
[HE5623] [388.3'22'0973]
ISBN 0-309-03803-0 ISSN 0361-1981

Sponsorship of Transportation Research Record 994

GROUP 1–TRANSPORTATION SYSTEMS PLANNING AND ADMINISTRATION
Kenneth W. Heathington, University of Tennessee, chairman

Public Transportation Section
John J. Fruin, Port Authority of New York and New Jersey, chairman

Committee on Bus Transit Systems
James C. Echols, Tidewater Transportation District Commission, chairman
Robert B. Deuser, Beiswenger Hoch & Associates, Inc., secretary
John J. Bakker, John W. Bates, Eugene T. Canty, Avishai Ceder, Frank Dicesare, John Dockendorf, Edward R. Fleischman, Marvin C. Gersten, Jack R. Gilstrap, Andrew Hollander, Ronald I. Hollis, Galen C. Larson, Herbert S. Levinson, Craig Miller, Subhash R. Mundle, Martin C. Nizlek, Howard J. Simkowitz, Robert N. Taube, F. V. Webster, Douglas L. Wentworth, Robert J. Zerrillo

Committee on Rural Public Transportation
Douglas J. McKelvey, Federal Highway Administration, chairman
Jon E. Burkhardt, Ecosometrics, Inc., secretary
David Banister, Bernard F. Byrne, John Collura, Richard Garrity, Robert T. Goble, Lawrence J. Harman, Kathleen F. Hoffman, Joyce H. Johnson, Robert G. Knighton, Norman G. Paulhus, Jr., Ervin Poka, Jr., Peter M. Schauer, Lawrence L. Schulman, Loretta E. Sharpe, Bruce S. Siria, Robert L. Smith, Jr., Susanna Stevens, Sheldon G. Strickland, Gregory C. Wilder

GROUP 3–OPERATION AND MAINTENANCE OF TRANSPORTATION FACILITIES
D. E. Orne, Michigan Department of Transportation, chairman

Committee on Bus Maintenance

Wm. Campbell Graeub and Adrian G. Clary, Transportation Research Board staff

Sponsorship is indicated by a footnote at the end of each paper. The organizational units, officers, and members are as of December 31, 1983.

Contents

Addresses of Authors

Anagnostopoulos, George, Transportation Systems Center, U.S. Department of Transportation, 55 Broadway, Cambridge, Mass. 02142
Baass, Karsten G., Department of Civil Engineering, Ecole Polytechnique, Montreal, Quebec H3C 3A7 Canada
Brown-West, Orikaye, Department of Civil Engineering, University of Connecticut, Storrs, Conn. 06268
Carter, Douglas W., Booz-Allen & Hamilton, Inc., 400 Market Street, Philadelphia, Pa. 19106
Chapleau, Robert, Department of Civil Engineering, Ecole Polytechnique, Montreal, Quebec H3C 3A7 Canada
Collura, John, Department of Civil Engineering, University of Massachusetts, Amherst, Mass. 01003
De Tore, John, The Boston Company, One Boston Place, Boston, Mass. 02108
Ercolano, James M., Transportation Planning and Engineering, 89-91 North Allen Street, Albany, N.Y. 12203
Etschmaier, Maximilian M., College of Engineering, University of Lowell, Lowell, Mass. 01854
Janarthanan, N., Department of Civil Engineering, University of Washington, Seattle, Wash. 98195
Kocur, George, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Mass. 02139
Levinson, Herbert S., Department of Civil Engineering, University of Connecticut, Storrs, Conn. 06268
Marwah, B. R., Department of Civil Engineering, Indian Institute of Technology, Kanpur-208016, India
McCollom, Brian E., Office of Methods and Support, UMTA, U.S. Department of Transportation, Nassif Building, 400 7th Street, S.W., Washington, D.C. 20593
McOwen, Paul, Department of Civil Engineering, University of Massachusetts, Amherst, Mass. 01003
Mundle, Subhash R., Booz-Allen & Hamilton, Inc., 400 Market Street, Philadelphia, Pa. 19106
Patnaik, S. B., Department of Civil Engineering, Engineering College, Burla Orissa, India
Rouphail, Nagui M., Department of Civil Engineering, Mechanics and Metallurgy, University of Illinois at Chicago, Chicago, Ill. 60680
Salpeas, Panagiotis P., Delaware Valley Regional Planning Commission, 21 South 5th Street, Philadelphia, Pa. 19106
Schneider, J., Department of Civil Engineering, University of Washington, Seattle, Wash. 98195
Umrigar, Farokh S., Department of Civil Engineering, B.V.M. Engineering College, Vallabh Vidyanagar-38812, India
Walker, W. Thomas, Delaware Valley Regional Planning Commission, 21 South 5th Street, Philadelphia, Pa. 19106
Zakaria, Thabet, Delaware Valley Regional Planning Commission, 21 South 5th Street, Philadelphia, Pa. 19106

Comparative Evaluation of Bus Route Costing Procedures

DOUGLAS W. CARTER, SUBHASH R. MUNDLE, and BRIAN E. McCOLLOM

ABSTRACT

Because policies regarding transit funding are changing at all levels of government, transit planners will be required to more carefully monitor existing bus systems as well as intensively examine the net cost or savings of proposed service changes. In the past two decades, research has been focused on demand and, hence, revenue estimation. Current financial constraints suggest that in the coming years more effort will be focused on operating cost estimation and the underlying relationships that affect expenditures. Although a variety of cost estimation techniques has been developed and used by transit operators, no single technique has been generally recognized as more accurate than the others. The purpose of the project, of which this paper is a product, is to develop a technique (i.e., the proposed method) that is sensitive to the salient cost characteristics of route-level service changes and is relatively easy to understand and apply. A key feature of this project involved a comparative analysis of the performance of the proposed method, and several other prominent cost techniques, against a scheduling-based route costing model.

Operating in an era of diminished public funding, transit agencies are pressed to find ways to reduce, or constrain, expenditure of scarce operating dollars. Many systems, facing severe financial constraints, have already initiated substantial service changes to balance costs with available funds. This recent trend in the transit industry will place greater demands on transit planners to forecast, with reasonable accuracy, the financial impacts of planned service changes. Although several approaches have been suggested or used in the past, no single technique or approach has proven entirely satisfactory. Recognizing the need for a reliable and relatively simple incremental cost estimation technique, UMTA commissioned this research effort to develop and test a bus route costing procedure.

The study is comprised of several interrelated tasks. The initial task entailed review and evaluation of cost estimation techniques used in the industry and procedures suggested in the technical literature. Following this assessment, a proposed method was developed for identifying incremental cost implications of bus route service changes. Next, a techniques test was conducted for the proposed method and other prominent models using actual and hypothetical service changes at the Metropolitan Transit Commission (MTC) in Minneapolis-St. Paul. On the basis of the test results, the proposed method and several other models were revised to enhance applicability and accuracy. The concluding step of the study entailed documentation of the proposed costing technique and preparation of a step-by-step manual for calibrating and applying the model.

The results of the cost estimation techniques test are described and evaluated. The test entailed application of five incremental cost models to 12 actual and hypothetical service changes at the MTC. The model results are compared and evaluated in terms of accuracy, sensitivity, and level of effort. Although the test was limited in scope (i.e., only 12 service changes were involved), it was guided by scientific research principles to ensure objectivity. The results of the techniques test cannot be assumed to be statistically valid for all situations, but the test does provide important insights into model applicability and relative strengths and weaknesses.

TEST FRAMEWORK

Four key groups participated in the techniques test: the consultant, MTC staff, the review panel, and UMTA staff. Each group performed a different role in executing the test. The consultant directed all test activities and was responsible for orientation of the MTC staff, quality control in model application and evaluation of test results. The MTC staff calibrated and applied each of the models to the 12 service scenarios comprising the test. The review panel, comprised of industry costing experts, provided direction and critiqued findings and analysis at critical points in the test. UMTA staff members also provided project guidance and assisted in the orientation of MTC staff to each of the cost estimation techniques.

Five costing techniques were calibrated and applied during the test:

- Proposed method,
- Modified Adelaide model,
- Peak and base cost allocation model,
- Two-variable cost allocation model, and
- Scheduling-based cost model.

Proposed Method

The proposed method focuses on driver-related costs because driver wages and benefits comprise by far the largest portion of cost impacts resulting from a service change. Other, nondriver, incremental costs are estimated using a traditional two-variable (i.e., hours and miles) cost allocation approach. The proposed method, like all techniques involved in the test, is sensitive only to those costs that typically vary in response to changes in the scale or characteristics of fixed-route service (i.e., variable costs). Fixed costs are neither considered nor estimated by the technique.

In the proposed technique, detailed analysis of driver cost begins with the number of platform hours, stratified by time of day, for both before and after the service change. Run-type ratios calibrated from existing driver and service schedules at the division level are modified to reflect the unique characteristics of the route being changed. Next, driver assignments, spread premium hours, and overtime hours are estimated by applying the calibrated ratios to the new platform hours at the division level. Weekly driver requirements are then estimated from assignment projections and the daily driver availability ratios are developed in the calibration phase. Finally, wage and benefits costs are determined in terms of regular, overtime, spread premium, show-up wages, paid absences, and variable and fixed benefits. The incremental wage and benefits cost is estimated by taking the difference between cost projections for before and after the service change. Nondriver costs are estimated by applying calibrated hour and mile rates to the net change in each resource unit.

Modified Adelaide Model

Developed by the British firm of R. Travers Morgan and Partners, the Adelaide model incorporates several novel approaches to cost estimation. One attractive feature of this model is a simplified driver scheduling algorithm that transcribes buses-in-service, by time period, into driver work assignments. This model is applied both before and after the service change to estimate the incremental cost impact.

The original Adelaide model does not address trippers because this type of assignment is not used in Australia or Great Britain. Trippers, however, occur with great frequency in the United States. To make the model meaningful for this study, both the scheduling and the costing algorithms were modified to address tripper assignments. Scheduling ratios were calibrated by assessing the weighted average of worked to pay hours for split runs, tripper combinations, overtime trippers, and part-time trippers separately for the morning and evening peak periods. Average worked and penalty hour costs were determined at the division level and appropriate rates were applied to route changes.

Application of the Adelaide model, as modified for this test, requires four primary steps that are applied at the route level for before and after the change. First, vehicle requirements are estimated by time of day based on round-trip time and service headways on the subject route. Second, vehicles in service are transcribed into driver requirements using a simplified scheduling algorithm. Third, incremental worked and penalty hours are estimated on the basis of division-wide scheduling and pay practices. Finally, the total route cost is estimated by applying the net change in worked hours, penalty hours, vehicle-miles, platform hours, and peak vehicles to calibrated resource unit costs. The incremental cost is the difference between before and after estimates.

Peak and Base Model

This model represents an enhancement of the traditional cost allocation models in that it allows hourly costs to vary relative to the amount of peak and base service. Two vehicle-hour cost rates (i.e., cost per peak hour, cost per base hour) are obtained by adjusting the total unit cost regularly produced in cost allocation. This adjustment is performed by calculating two indices--one representing relative labor productivity (i.e., pay hours per platform hour by time of day) and the other representing the ratio of peak to base service.

Cost Allocation Model

The cost allocation model is probably the most commonly used method of estimating cost impacts of service changes. The model is predicated on the concept that cost is a function of one or more resource quantities, such as vehicle-hours, vehicle-miles, or peak vehicles. Unit cost rates per resource unit are found by assigning each individual expense in the system's financial statement to a resource, summing the expenses, and dividing by the respective resource quantity. To find the cost of a service change, these cost rates are simply multiplied by the net change in each respective resource and then summed. The method is easy to understand, calibrate, and apply, but it may underestimate or overestimate key cost elements such as driver wages. This error will increase in magnitude to the degree that the service change characteristics differ from the system average characteristics.

Scheduling-Based Cost Model

As part of the techniques test, the consultant, in conjunction with MTC staff, developed a scheduling-based cost model against which all other models were tested. The model uses complete run-cut information and system cost characteristics to develop cost estimates. Regular driver costs are based on the number of runs, overtime hours, and spread premium hours as scheduled by RUCUS software (MTC's normal scheduling procedure). Extra board costs are based on tripper pay requirements as determined by MTC's manual assignment (RUCUS does not explicitly address tripper pay requirements). Driver benefits (i.e., paid leave, FICA, pension, fixed benefits) are developed based on wages, past experience, and contractual provisions. Nondriver, variable operating costs are estimated with a cost allocation approach corresponding to that used in the proposed method. The model produces a cost estimate that MTC staff and the consultant believe best reflects true cost impacts.

The scheduling-based cost model was applied to the entire division for each route change because routes are not generally scheduled independently, and routes frequently contain foreign pieces (i.e., work from another route). The incremental cost impact is determined by taking the differences between the cost estimates for before and after the change. It should be noted that, unlike the modified Adelaide model, this model need only be applied once for the before condition--assuming that all route changes occur in the same division.

Service Scenarios

Route changes were the basic unit of analysis during the techniques test. A summary of the 12 service scenarios used in the test is given in Table 1. Route changes encompassed a variety of time periods, including weekday (peak only), weekday (midday only), weekday (all day), and weekend.

The service scenarios are comprised of three basic change types: change in running time, addition or deletion of an entire route, and addition or deletion of single trips. Changes in running time may result from any number of factors including extending or shortening a route, changes in load factors, and changes in traffic conditions or controls. All of these can contribute to a change in driver and vehicle use. Additions or deletions of entire routes, or of single trips, are situations faced by transit planners in tailoring service to match new fiscal or ridership conditions. All of these conditions can contribute to changes in driver and vehicle use, with corresponding cost implications.

It should be noted that the magnitude of the service changes was generally quite small. Daily

TABLE 1 Service Scenarios Used in Model Testing

Scenario Number	Type of Change	Description	Net Change in Daily Hours	Percent of Division Hours
1	Weekday-Peak Only	Extend an express route/MTC Express Rte. 35C	2.50	0.121
2	Weekday-Peak Only	Reduce service by half/MTC Express Rte. 35C	(10.05)	0.484
3	Weekday-Peak Only	Discontinue one A.M. and one P.M. Trip MTC Express Rte. 35LU	(2.88)	0.139
4	Weekday-Peak Only	Discontinue one A.M. and one P.M. trip MTC Local Rte. 47	(2.12)	0.102
5	Weekday-Midday Only	Discontinue midday service/MTC Local Rte. 9	(32.70)	1.576
6	Weekday-Midday Only	Reduce midday service by half/MTC Local Rte. 2	(6.67)	0.322
7	Weekday-All Day	Double midday service/MTC Local Rte. 2	22.27	1.074
8	Weekday-All Day	Discontinue weekday service/MTC Local Rte. 47	(63.35)	3.054
9	Weekday-All Day	Reduce service on express route MTC Express Rte. 52B	(15.68)	0.756
10	Weekend	Discontinue Saturday service/MTC Local Rte. 21	(116.22)	1.142
11	Weekend	Discontinue Sunday service/MTC Local Rte. 21	(79.42)	0.871
12	Weekend	Discontinue six Sunday trips/MTC Local Rte. 9	(4.03)	0.044

changes in vehicle-hours range from 2.12 to 116.22 hr. This translates to a range of less than 0.05 percent of division hours to about 3 percent of total hours. Specifically, eight of the scenarios represent a change of less than 1 percent of total division hours, and four scenarios represent changes of between 1 and 3 percent of service hours.

EVALUATION OF TEST RESULTS

Evaluation of the test results was an interpretive process based on simple statistical measures. An important consideration throughout the evaluation was the limited sample size. The test entailed application of five cost models to a total of 12 route-level service changes. All of the service changes occurred at one transit system and within a single operating division. The sample size suggests that the test results may not reflect actual model capabilities under all circumstances. The test is intended to provide an indication of how well these cost models perform against one another under field conditions, and does not preclude additional testing.

The incremental cost estimates produced in the techniques test are given in Table 2. Using the scheduling-based cost estimate as a reference, the annualized incremental cost impacts of the 12 service changes ranged from $4,893 (Scenario 12) to $780,897 (Scenario 8). These cost estimates formed the basis for the evaluation of model performance.

The evaluation of test results focused on three primary areas of concern: model accuracy, model sensitivity, and level of effort. Each of these issues is discussed further hereafter.

Model Accuracy

A significant limitation is placed on this element of the test because a true cost value does not exist; that is, it is practically impossible to determine the actual cost attributable to a change in service. For the purposes of this test, the scheduling-based cost model estimate serves as the yardstick against which the other models are measured. This comparison provides a reasonable indication of relative model accuracy.

Relative model accuracy was examined using the percentage of deviation from the scheduling-based

TABLE 2 Annualized Incremental Cost Estimates

	Incremental Cost Model				
Scenario	Scheduling-Based	Proposed	Adelaide	Peak/Base	Cost Allocation
1	$ 25,584	$ 15,692	$ 47,496	$ 16,870	$ 16,532
2	(145,652)	(93,116)	(104,096)	(96,541)	(95,193)
3	(29,902)	(30,239)	(17,019)	(29,537)	(29,092)
4	(22,019)	(22,265)	(36,809)	(20,571)	(20,271)
5	(229,310)	(267,770)	(239,678)	(271,132)	(275,828)
6	(61,597)	(71,799)	(58,023)	(51,321)	(52,285)
7	178,627	155,202	154,671	166,393	183,696
8	(780,897)	(701,155)	(785,099)	(622,610)	(661,758)
9	(209,973)	(175,949)	(154,298)	(173,694)	(173,738)
10	(233,830)	(225,595)	(234,569)	(199,980)	(203,405)
11	(178,704)	(175,187)	(200,180)	(151,820)	(154,430)
12	(4,893)	(8,983)	(4,305)	(7,438)	(7,570)

cost estimate as the primary measure. This method for evaluating relative model accuracy examines the percentage difference between each model's results and the best estimate. This measure can be examined from several different perspectives, including

- By type of service change and
- By size of service change.

Each of these measures, as applied in the techniques test, is further discussed.

Percent Deviation by Type of Service Change

This measure examines the percentage of deviation from the scheduling-based cost estimate by type of scenario for each model (Table 3). All models show substantial variability in their performance for peak period changes, with the modified Adelaide model experiencing the greatest overall deviation in the test. It should be noted that the proposed method comes within 1 percent of the scheduling-based cost estimate two out of four times. Each of the models appears more stable on midday only and all-day service changes. The weekend changes offer a mixed bag of performance--all models perform reasonably well on two of three changes. The models perform poorly on one scenario that entails a change of less than 1/20th of 1 percent of total division hours.

Percent Deviation by Magnitude of Change

Another way to view model accuracy is based on how well it performs in relationship to the magnitude of the service change. This relationship is shown in Figures 1-4 for the proposed method, modified Adelaide model, peak and base model, and cost allocation model, respectively. One preeminent trend is evident for each model--overall accuracy improves with increases in the magnitude of the service change. This trend is most pronounced in the proposed method and the modified Adelaide model. The trend also exists in the peak and base and cost allocation models, although to a smaller degree. These two models show lower variability, and they

TABLE 3 Percentage of Deviation from Best Cost Estimate

Scenario	Type of Change	Proposed Method	Adelaide Model	Peak/Base Model	Cost Allocation Model
1	Weekday-Peak	(39)	86	(36)	(35)
2	Weekday-Peak	(36)	(29)	(34)	(35)
3	Weekday-Peak	1	(43)	(1)	(3)
4	Weekday-Peak	1	67	(7)	(8)
5	Weekday-Midday	17	5	18	20
6	Weekday-Midday	17	(6)	(17)	(15)
7	Weekday-All Day	(13)	(13)	(7)	3
8	Weekday-All Day	(9)	1	(15)	(15)
9	Weekday-All Day	(16)	(27)	(17)	(17)
10	Weekend	(4)	1	(14)	(13)
11	Weekend	(2)	12	(15)	(14)
12	Weekend	84	(12)	52	55

( ) Denotes percent underestimated

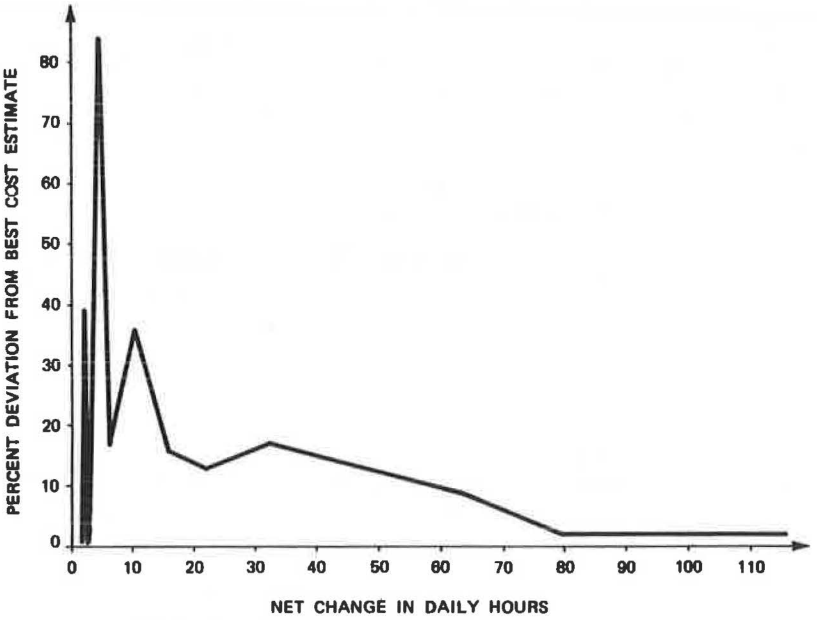


FIGURE 1 Relationship of model accuracy to magnitude of service change—proposed method.

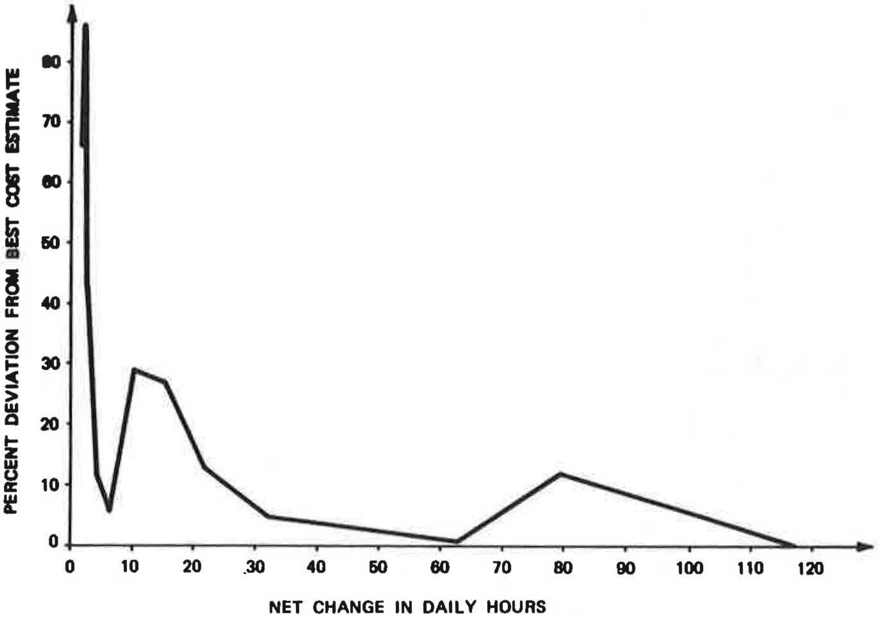


FIGURE 2 Relationship of model accuracy to magnitude of service change—modified Adelaide model.

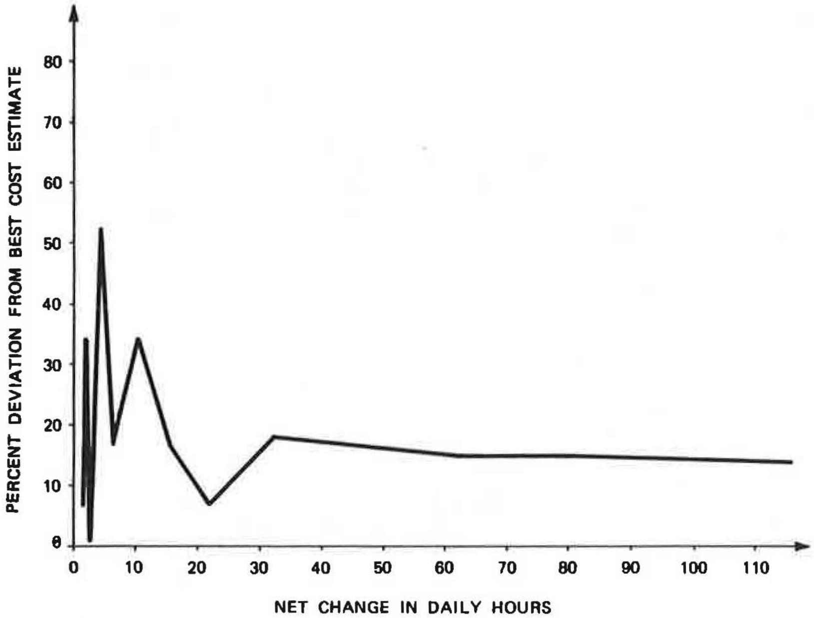


FIGURE 3 Relationship of model accuracy to magnitude of service change—peak and base model.

also exhibit greater deviation from the scheduling-based estimates overall.

Although each of these measures examines model accuracy in a different light, one common theme appears to prevail: All of the models tested exhibit high variability in their ability to replicate scheduling-based cost estimates for minute service changes (i.e., less than 1 percent of division hours). Overall performance and consistency improve with increases in the magnitude of the service change. Although the proposed method and the modified Adelaide model appear highly accurate on many individual scenarios, they are also quite inaccurate on several scenarios. In comparison, the peak and base and cost allocation models tend to be less accurate overall, but they also show less variability in their performance.

Model Sensitivity

The sensitivity of a model was measured by examining the amount of variation in its unit cost estimates of different service changes. It has been assumed that the unit cost (i.e., cost per hour) of a service change should be variable, reflecting the differential cost impacts of particular service characteristics (e.g., peak-only service versus weekend service, tripper versus regular runs, express versus local service). When the unit costs produced by a

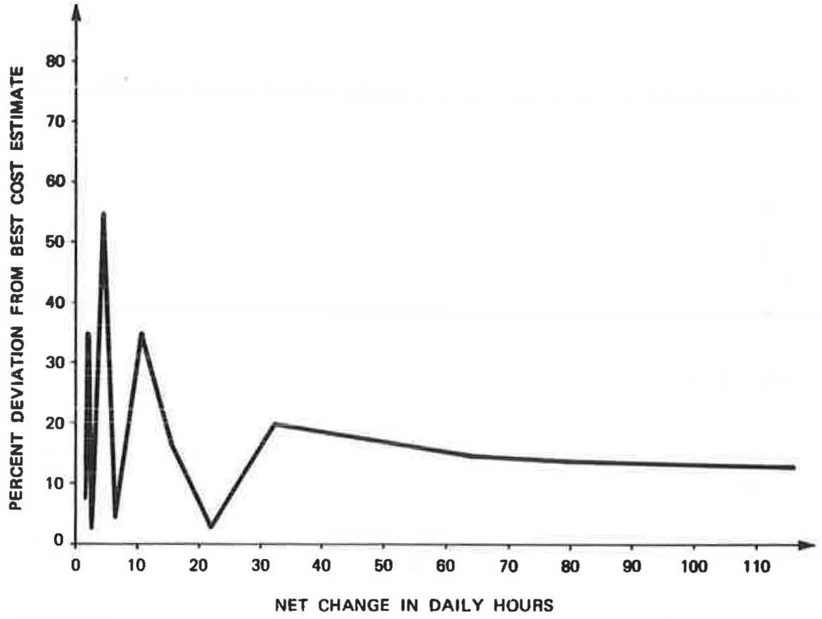


FIGURE 4 Relationship of model accuracy to magnitude of service change—cost allocation model.

model are relatively constant over a series of service changes, the model's sensitivity may be questioned.

Evaluation of model sensitivity is an interpretive process. The question of why one model shows greater variance than another in unit costs must be considered. This is essential because variation may be due to inaccurate cost estimates as well as to sensitivity to particular conditions. In the test, this analysis was conducted by contrasting sensitivity findings with accuracy results by model.

The primary measure of model sensitivity in this test is the coefficient of variation (CV). The CV is calculated as the ratio of a model's standard deviation to its mean unit cost (i.e., cost per hour) for all the test situations. A low CV value indicates that all unit costs are grouped in a narrow band around the mean. A high CV value indicates a high degree of variance from the mean unit cost.

The results of this test, given in Table 4, indicate that the proposed method comes closest to replicating both the mean hourly cost and the CV produced by the scheduling-based cost model. The modified Adelaide model produces the highest CV value, which exceeds the scheduling-based cost model's coefficient by more than 60 percent. This is partially attributable to the inaccurate cost estimates produced by the modified Adelaide model and demonstrated in the accuracy evaluation. The peak and base and cost allocation models produced coefficient of variance values only slightly lower than that of the proposed method. However, the mean unit cost estimate from these two models was significantly below the scheduling-based estimate.

TABLE 4 Model Sensitivity Measured by the Coefficient of Variance

Model	Aggregate for 12 Scenarios Mean Cost* Per Hour	Standard Deviation	Coefficient of Variance
Scheduling-Based	$39.4	$10.1	0.26
Proposed Method	37.2	6.2	0.17
Modified Adelaide Model	41.0	17..2	0.42
Peak/Base Model	34.7	5.2	0.15
Cost Allocation Model	34.6	5.2	0.15

* Incremental Cost

Level of Effort

Another important consideration in model evaluation is the level of effort required to produce an incremental cost estimate. The level of effort needed to use a particular model falls into two categories, calibration and application. Each model must be calibrated before actual use, with the level of effort proportional to the number of steps required and the amount of time required. When applied, the level of effort is primarily a function of the data inputs required and the time needed to apply the algorithms.

Model Calibration

The purpose of model calibration is to prepare the costing method for application to route change scenarios. Calibration requires three basic activities: data collection, data processing, and calculation of unit costs and coefficients. A primary source of data for each of the models included in this test is the Section 15 accounting report. Several of the test methods required additional information about driver assignments, which was obtained from assignment and dispatching data.

Because each of the test models uses commonly available data for calibration, the level of effort required in this activity was examined in terms of relative time to calibrate each model. In the techniques test, the proposed method required the greatest amount of time for calibration--about 24 working hours. The modified Adelaide model also required a high level of effort, about 18 hours total. The peak and base model, as calibrated at the test site, required expenditure of 10 person-hours. Each of these models required analysis of scheduling practices, which accounted for a large portion of the time expended. The remaining two models, the scheduling-based cost and the cost allocation models, required 3 hr and 1 hr, respectively.

Although the level of effort required in model calibration varies significantly, it should be noted that calibration occurs only once a year. The effort expended in the calibration phase can be spread over the number of times the technique is applied, thus lowering its burden significantly. Because calibration data are generally valid for a year, the level of effort required for model application may be of greater concern to potential users.

Model Application

The level of effort required in applying costing techniques is primarily a functon of the data input needs and the time required to complete application algorithms. Each of these elements is discussed hereafter.

Data Requirements for Application

Each model's application can be classified according to the amount of data needed to apply the model. The two-variable cost allocation model can be applied when only the magnitude of the service change (i.e., net change in miles and hours) is known. The peak and base model and the proposed method require not only the scale of the change but the span as well (i.e., time periods in which change occurs). The modified Adelaide model estimates incremental cost based on changes in headways, round-trip time, platform hours, and vehicle-miles--thus application occurs later in the planning process. The scheduling-based cost model uses complete run-cut information to predict cost implications and, therefore, can only be applied after scheduling is completed.

Relative Time Requirements for Model Application

Experience in the techniques test indicated that the cost allocation and the peak and base models required the lowest level of effort, with complete application averaging about 5 to 10 min per scenario. The proposed method required between 35 and 50 min for application; the major time driver is whether the change occurs on a weekday or weekend schedule. Application of the modified Adelaide model averaged 30 to 40 min when the average headways and round-trip time had been determined for the five time periods. Establishment of average headways and round-trip times for before and after the change increases the expended time by 1 to 3 hr. Thus, total application time, relative to the other models, is generally 1.5 to 3.5 hr per scenario.

Application of the scheduling-based cost model averaged between 30 and 40 min per scenario after all required scheduling data were made available. To make a valid comparison with the other models, scheduling time must be included. At the test site, legal runs are scheduled at the division level using RUCUS software, and trippers are scheduled manually. The entire process took 14 to 16 hr per scenario. This brings the total application time up to 14.5 to 16.5 hr per service change--a level of effort not likely to be expended in the planning phase of service development.

Although the actual level of effort required to apply these models at other properties may vary somewhat with data processing capabilities, the overall relationship of the models should remain constant.

CONCLUSIONS

Although the techniques test was limited in scope and an actual value for incremental costs was not available, several interesting conclusions are suggested by the study results. First, none of the costing techniques appear to be consistently accurate for extremely small service changes (i.e., less than 1 percent of total division hours). Each of the cost models experiences high variability and substantial deviation from the best cost estimate for service changes of this magnitude. Second, the size of the estimated cost implications of minute service changes (i.e., less than 1 percent) is so small that transit properties may not wish to expend the resources necessary to estimate these costs. It may be more productive to focus service planning resources on more substantive, although still small, service changes.

The proposed method and the modified Adelaide model were the best overall performers in this test. The proposed method performed best in some measures of accuracy (i.e., aggregate rank, percentage deviation from scheduling-based estimates) and in measures of sensitivity (i.e., mean unit cost and coefficient of variation). The proposed method performs reasonably well in the level of effort category. The modified Adelaide model also performs well in measures of accuracy (i.e., magnitude of deviation and percentage deviation from the best estimates), but it is not as good a performer in sensitivity measures or level of effort. Although these two models frequently come closest to replicating the scheduling-based cost model, they also incur substantial variations from the best estimates in several instances (e.g., minute service changes). They are both deterministic models and are generally sensitive to cost differentials of a variety of service changes.

The peak and base model and the cost allocation model exhibit similar performance trends in all evaluation categories. Each of these models experiences less variability, even in minute changes, than do the proposed method and the modified Adelaide model. This is chiefly attributable to their average costing algorithms, which are less sensitive to the cost differentials of a variety of service changes. Some degree of sensitivity is surrendered, but simplicity in model application is maintained. On the larger of the small service changes (i.e., 1 to 3 percent of division service), these models are the poorest performers.

The techniques test provides some insights into the relative performance of each of the subject models. Both the proposed method and the modified Adelaide model represent more sophisticated attempts to simulate the complex factors driving incremental driver wage and benefits cost. The peak and base and cost allocation models, on the other hand, use a statistical approach in which systemwide average characteristics determine the extent to which incremental costs are affected. The accuracy, sensitivity, and ease of use evaluation measures suggest that no single model is preferred for all situations.

The use of a particular model would be a function of the extent of the service changes and the use of the cost estimates. For example, investigation of the cost consequences of a relatively minor service change would suggest the use of the peak and base or cost allocation model. The increased sensitivity and complexity of the other procedures do not appear to increase relative model accuracy for minute bus service modifications. This may be attributable to the numerous intermediate solutions (e.g., number of trippers and drivers) possible. For more substantial service changes, the proposed and modified Adelaide models may be preferred. In cases in which the cost impacts are expected to be relatively high, use of a more rigorous, and potentially more accurate, evaluation tool may be warranted.

Another issue related to the selection of an incremental costing procedure is the intended use of the resulting cost estimates. For a preliminary investigation of a wide range of bus service options, the simplistic techniques may be appropriate. In this case, the resources required to apply the technique would not unduly constrain the number of service changes that could be investigated. If a relatively limited number of changes were considered for implementation, a more accurate, but more time-consuming, model might be appropriate. Such an approach is consistent with other transportation analyses in which sketch-planning techniques are applied initially to screen a large field of options and then followed by more rigorous and detailed procedures for the most promising scenarios.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Estimating Bus Ridership

HERBERT S. LEVINSON and ORIKAYE BROWN-WEST

ABSTRACT

A route-based approach to estimating bus ridership is described. Bus riders on a typical Hartford, Connecticut, route were classed by walking distance and car ownership status, and compared to the number of dwelling units in each status. A series of "ridership penetration curves" shows how the number of bus riders per dwelling unit relates to car ownership and walking distance. For each level of car ownership, these curves decline with increasing walking distance. They show a drop of about 5 rides per 100 dwelling units for every 100-ft increase in walking distance, and a decrease of about 10 rides per 100 dwelling units when the first car is acquired and again when the second car is acquired. The data appear consistent with patterns derived from origin-destination surveys.

Public transportation planning and operation in today's urban environment increasingly concentrate on adjustments to existing services. They emphasize ways to increase transit service efficiency and to reduce operating deficits, instead of trying to assess impacts of large-scale investments. This involves adapting service to changing ridership patterns and cutting or restructuring service to bring costs and revenues into better balance. It calls for route-sensitive ridership estimation techniques that are keyed to fine-tuned service changes.

Much work, of course, has been done on estimating transit ridership. There is an extensive literature on network-based modal split models keyed to the relative disutilities of car and bus travel (i.e., logit modal split models). At the other end of the spectrum there is a growing body of elasticity factors that are keyed to service frequencies, fares, and travel times. Neither of these techniques properly addresses the question: If a new route is extended into a residential suburb, how many riders will it attract? Conversely, if a route is cut back, what will be the net loss in patronage?

Most of the current ridership estimation techniques are either too complex or too general to provide timely and meaningful responses to these fine-grained service changes. For these reasons, simplified and reliable estimating techniques that can be applied at the route level remain an important research need (1).

RESEARCH APPROACH

The results of a ridership research study conducted during 1981 and 1982 for the Connecticut Department of Transportation are discussed. The research objective was to develop a method for quickly estimating the ridership impacts of bus service changes in Connecticut cities (2).

Pilot surveys were conducted on six Hartford bus lines in June 1981 to identify parameters and refine the research approach. This was followed by a resurvey of riders on Line U-3 in June 1982. The ridership data for U-3 were compared with 1980 census data to obtain "penetration ratios" (ridership rates) by car ownership and walking distance strata. Finally, comparisons, applications, and extensions of the research were developed.

The research approach is shown in Figure 1. Detailed steps were as follows:

1. June 1981 on-board surveys obtained the travel patterns of 1,224 inbound riders out of a total of 21,130 weekday (two-direction) riders. The

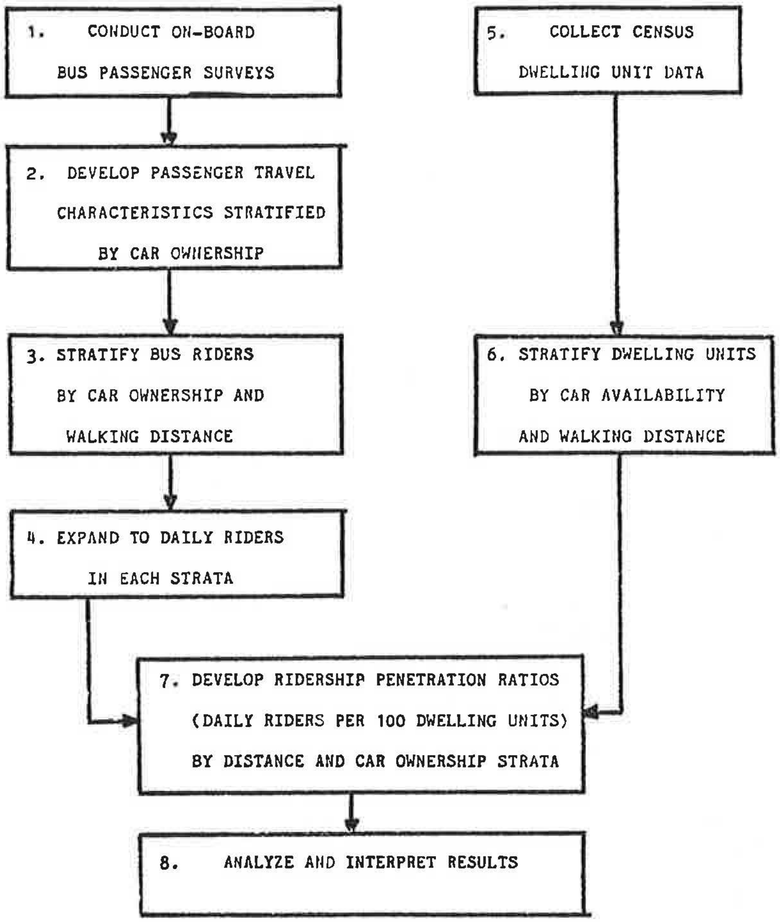


FIGURE 1 Research approach.

June 1982 survey obtained information on 515 riders out of a total of 2,213 daily weekday riders.

2. Passenger travel characteristics were summarized and stratified by car ownership.

3. Bus riders were further stratified by car ownership status and walking distance to bus stop.

4. Sample data were expanded to represent the average daily two-way ridership.

5. Dwelling unit data were obtained on a block and tract basis from the 1980 Census.

6. The number of dwelling units within various walking distances of bus lines by car availability status were estimated. In general, where two or more bus lines shared a census tract corridor, the tract data were distributed equally. However, where natural barriers (e.g., rivers) or man-made barriers (e.g., railroad yard or track) formed a barrier or restricted access to a specific bus line within a tract, most of the tract was allocated to the bus line that had easy access.

7. Ridership penetration ratios were obtained by dividing the bus riders in any stratum into the number of dwelling units (DUs) in that stratum, for both individual lines and all lines. That is,

$$\text{Penetration ratio} = \text{Riders}_{ij}/\text{DU}_{ij}$$

where i is walking distance stratum and j is DU stratum.

8. The resulting relationships were compared with available information for other cities, as well as with information from the initial surveys. Finally, applications and extensions of the research were developed.

RIDERSHIP SURVEYS

The U-3 bus route runs outbound from downtown Hartford to the Wethersfield Shopping Center (6.20 miles) and inbound from the shopping center to downtown (6.86 miles). It forms the southern continuation of Line U-1 from Bishop's Corner in West Hartford and Line U-2 (inbound from Bloomfield and part of West Hartford). It serves part of Southeast Hartford, Wethersfield, and the northern fringes of Rocky Hill. Its passenger generating area overlaps that of other bus routes in some sections, and it shares the same corridor in other places.

The ridership surveys were conducted between June 2 and June 10, 1982, between 5 a.m. and 7 p.m. The surveys obtained 515 responses of which 359 (70 percent) represented home-based trips, 80 (16 percent) involved transfers, and 76 (14 percent) were incomplete (see Figure 2). The 359 usable home-based responses accounted for 16 percent of the daily ridership (both directions) of 2,213 persons. This produced an expansion factor of 6.16 that was subsequently applied to the survey data (Table 1).

BUS RIDERSHIP PENETRATION

The general distribution of bus riders by car ownership status and walking distance is given in Table 2.

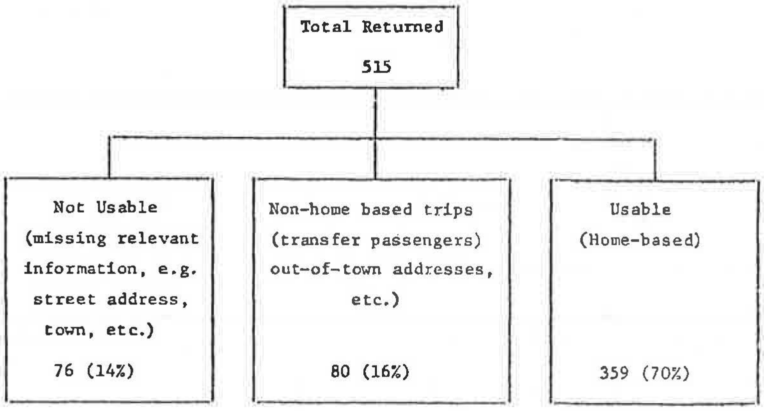


FIGURE 2 Hartford bus ridership survey, 1982: questionnaire returns.

TABLE 1 Hartford Bus Ridership Survey, June 1982: Comparison of Sample Responses with Actual Bus Riders (Line U-3)

Daily Weekday ConnTransit Riders (two-way)	No. of Questionnaires Returned (inbound riders)	Usable Questionnaires Returned	Ratio of Usable Questionnaires Returned to Weekday Riders	Expansion Factor[a]
2,213	515	359	0.1622[b]	6.16

[a] To represent two-way ridership.

[b] 0.3248 for inbound riders.

TABLE 2 Hartford Bus Ridership Survey, 1982: Expanded Two-Way Daily Ridership by Car Ownership Status and Walking Distance (Line U-3)

Approximate Walking Distance (ft)	No. of Respondents (x 6.16)	Percentage	No. of Cars Owned 0	1	2	3+	2+
200	1,140	51.5	407	493	234	6	240
400	671	30.4	234	308	123	6	129
600	240	10.9	86	105	37	12	49
800	117	5.3	31	37	37	12	49
1,000	42	1.9	12	12	6	12	18
Total	2,211	100.0	770	955	437	49	486
Percentage	100		34.8	43.2	19.8	2.2	22.0

Data are summarized for six walking distance strata as follows:

Stratum (ft)	Approximate Average or Midpoint (ft)
0-300	200
300-500	400
500-700	600
700-900	800
More than 900	1,000

Walking Distance

Approximately 52 percent of all riders lived within 200 ft of Line U-3, 82 percent within 400 ft, and more than 90 percent within 600 ft.

Car Ownership

Approximately 35 percent of all riders came from zero-car households, 43 percent from one-car households, and 22 percent from multicar households.

Detailed Penetration Curves

Ridership penetration curves were developed by relating the bus ridership data given in Table 2 to the 1980 dwelling unit statistics given in Table 3. The resulting ridership penetration curves and values for Line U-3 are given in Table 4 and shown in Figure 3. Ridership penetration ratios by walking distance stratum decrease from the 58 daily rides per 100 DUs for dwellings within 200 ft of a bus stop to 48 for those within 400 ft, 39 for those within 600 ft, and about 20 for those beyond 600 ft.

The patterns vary, however, for each level of car ownership.

- Daily ridership per 100 DUs for zero-car households drops from 65 at 200 ft to 22 at 1,000 ft. It averages 56 overall.
- Daily ridership per 100 DUs for one-car households drops from 55 at 200 ft to 15 at 1,000 ft. It averages 48 overall.
- Daily ridership per 100 DUs for multicar households drops from 50 at 200 ft to 20 at 800 ft. It averages 38 overall. (Because of small responses for 3+ car households it was necessary to group all multicar households into a single category.)

TABLE 3 1980 Car Availability per Dwelling Unit (census tract and block statistics) Stratified by Average Walking Distance from Nearest Bus Stop (Line U-3)

Approximate Walking Distance (ft)	No. of Dwelling Units	Percentage	No. of Cars Owned				
			0	1	2	3+	2+
200	1,979	42.3	599	896	468	16	484
400	1,398	29.9	442	629	308	19	327
600	610	13.0	191	263	109	47	156
800	475	10.2	97	132	175	71	246
1,000	216	4.6	55	80	50	31	81
Total	4,678	100.0	1,384	2,000	1,110	184	1,294
Percentage	100.0		29.6	42.8	23.7	3.9	27.6

TABLE 4 Hartford Bus Ridership Survey, 1982: Ridership Penetration for Line U-3 (daily rides per 100 DUs)

Walking Distance (ft)	No. of Cars Owned per Dwelling Unit					All Ownership
	0	1	2	3+	2+	
200	67.95	55.02	50.00	37.50	49.59	57.60
400	52.94	48.97	39.94	31.58	39.45	48.00
600	45.02	39.92	33.94	25.53	31.41	39.34
800	31.96	28.03	21.14	16.90	19.92	24.63
1,000	21.82	15.00	12.00	38.71[a]	22.22[a]	19.44
All distances	55.63	47.75	39.37	26.63	37.56	47.26

[a] Data are questionable because of small sample size.

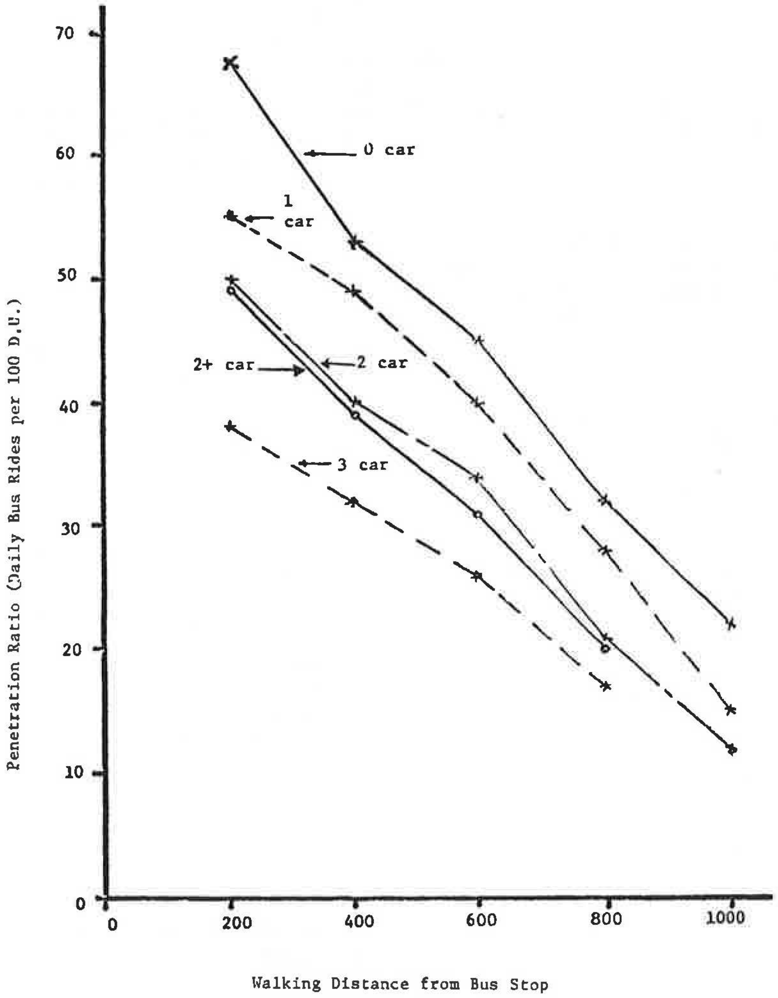


FIGURE 3 Ridership penetration curves for Line U-3 (1982 data).

The ridership penetration curves for zero-car, one-car, and multicar households follow expected patterns. Ridership decreases as distance from the bus stop increases and as car ownership increases. The decreases appear to be linear for each level of car ownership and suggest the following relationships:

$$R_0 = 77.91 - .05652X \tag{1}$$

$$R_1 = 67.68 - .05049X \tag{2}$$

$$R_2 = 59.84 - .04740X \tag{3}$$

$$R_{2+} = 59.36 - .048525X \tag{4}$$

where

X = distance from bus stop (ft);
R_0 = daily rides per 100 DUs, zero-car households;
R_1 = daily rides per 100 DUs, two-car households; and
R_{2+} = daily rides per DUs, 2+ car households.

The average values, from which these formulas were derived, had correlations generally exceeding 0.9. An inspection of these curves shows a drop of about 5 rides per 100 DUs for every 100-ft increase in walking distance. There is also a decrease of about 10 rides per 100 DUs when the first and, again, second cars are acquired. This suggests the following general formula for approximating bus ridership:

$$R_i = 80 - 10c_i - .05X_i \tag{5}$$

where c_i is cars/DU in stratum i at distance X_i and R_i is rides per 100 DUs per day in stratum i.

Comparison of Results

The penetration ratios compared with those obtained from origin-destination surveys are given in Tables 5 and 6. The data appear consistent with those for typical "small" cities; more precisely, they are correct in scale or order of magnitude.

TABLE 5 Estimated Transit Rides per Person per Day in U.S. Cities (1960-1970s) (*3*)

	Cars per DU		
City Size	0	1	2+
Large	0.70	0.30	0.20
Medium	0.40	0.20	0.10
Small	0.30	0.15	0.10

TABLE 6 Estimated Transit Rides per DU per Day in U.S. Cities (1960-1970s) (*3*)

	Cars per DU		
City Size	0	1	2+
Large	1.30	0.95	0.76
Medium	0.79	0.63	0.38
Small	0.59	0.48	0.38
Hartford Line U-3 service area only	0.56	0.48	0.39

IMPLICATIONS AND EXTENSION

The penetration curves are based on a bus service frequency of approximately 20 min and a fare of $0.60. They can be applied in the following manner to obtain an initial estimate of route ridership:

1. Delineate the target area of the bus route or route change.
2. Identify the population within the "tributary area" in appropriate distance bands, discounting for competing lines. Stratify this population in distance bands or car ownership or availability, or both.
3. Apply the penetration curves or the formula $R_i = 80 - 10c_i - .05X_i$.
4. If there are regional generators along the line (outside the central area), their ridership potential should be added to the estimates obtained in Step 3.
5. Estimates should be made of the desired service frequency and fare structure.
6. Apply appropriate headway and fare elasticity data, assuming a 20-min headway and a $0.60 fare as a base.

The approach provides a much-needed refinement to the "riding habit" approach used by many transit agencies. The logical next steps should involve a small-scale test of the ridership penetration curves to access their real-world application and possible adjustments in scale or amplitude.

Additional surveys in Hartford would provide a basis for assessing the effects of route type on these relationships. Similar analyses in other cities would be useful in identifying the impacts of city type or central business district character. In addition, further research is also needed to better pinpoint the effects of competing line transfer passengers and non-home-based trips.

ACKNOWLEDGMENT

The assistance and insight of Charles Dougan, Director of Research, Connecticut Department of Transportation, is appreciated. Work was performed through the Joint University Research Advisory Council.

REFERENCES

1. Bus Route and Schedule Planning Guidelines. NCHRP Synthesis of Highway Practice 69. TRB, National Research Council, Washington, D.C., 1980.
2. H.S. Levinson and O. Brown-West. Estimating Bus Ridership. Joint University Research Advisory Council, University of Connecticut, Storrs, April 1983.
3. H.S. Levinson. Characteristics of Urban Transportation Demand. UMTA, U.S. Department of Transportation, 1978.

Publication of this paper sponsored by Committee on Bus Transit Systems.

FRACAS: A Strategic Planning Model for Bus Transit Systems

GEORGE KOCUR and JOHN DE TORE

ABSTRACT

The Fare and Route Analysis Computer Aided System (FRACAS) is a strategic planning model for transit systems. It is implemented on an Apple II microcomputer. FRACAS both generates and evaluates service and fare options for local transit systems, helping the analyst achieve system goals. It accepts data on objectives, operating conditions, and existing service and market sensitivities, and it computes the best number of routes, route length, headway, and fare for the time periods and area analyzed. The user can override the model in any service or fare aspect. FRACAS also computes a set of 33 performance measures as part of its output. The model is a flexible approach to the problems of adjusting service and fares to meet budget constraints, and it also treats express service, vehicle size issues, and peak versus off-peak service issues, which are important elements of strategic planning in many systems. To enhance its usability, FRACAS is entirely menu driven with extensive error checking and recovery; no programming knowledge is required of the user.

The Fare and Route Analysis Computer Aided System (FRACAS) program is a strategic planning tool designed to interactively help transit managers and planning staff with the task of establishing fare and service policy. For a given transit system, corridor, or route, FRACAS computes a combination of service and fare that best achieves system objectives. The service is defined by the number of routes in the analysis, their average length, the average headway, and the fare. Express and local service and peak and off-peak time periods can be treated jointly. FRACAS computes the service levels, ridership, revenues, and costs of options and provides statistics on bus-miles, bus-hours, and passenger-miles, for example. These results are displayed in a four-page report on the computer monitor and can also be printed out.

Specification of the service area is quite general: a corridor within the system or even a particular route can be specified. In addition, the objective the model works toward can be varied, as well as the number and choice of variables that the model is given control over. For example, the model can specify the optimum headway with routes and fares fixed, or it can find the best headway and routes, given a fixed fare. In the extreme, all variables can be user specified. In this case, FRACAS simply operates as an evaluation tool, estimating ridership, revenue, cost, and service impacts. In all cases, FRACAS estimates a full set of financial and performance statistics for the service specified.

Because the output procedure typically takes 90 sec or less, the model can be run repetitively to develop an understanding of the fundamental choices affecting the performance of a particular transit system. FRACAS uses system-, corridor-, and route-level data typically available in a transit agency. No additional data collection is required. All data entry is through the five FRACAS input menus, which are user oriented and provide data checking and help in real time. FRACAS is a stand-alone program, not linked directly to any other program or package. No special skills are required to operate it; it is a "turnkey" system that requires no programming knowledge.

INFORMATION FLOW

The flow of information between the user and FRACAS is described in this section. Because one of the goals in designing FRACAS was to produce a system that was user friendly, there was a substantial amount of effort expended to organize the input data into intuitive groups and to present the outputs in an easily interpretable set of tables.

In designing FRACAS, several questions had to be answered. First, what variables need to be determined by the system to make it an effective strategic planning tool? Second, what data are readily available? And third, what level of detail should the model cover? In other words, where on the scale between a sketch-planning model and a network model should this model lie?

The basic approach is to use an optimization model to solve for the best service and fare levels using a small set of input variables described in this section. The decision variables are the number of routes in the corridor studied, the average route length, the average fare, and the average headway.

The model applies only to a transit system consisting primarily of radial routes extending from the central business district (CBD). The analyst may optimize the system with respect to one of three objectives: (a) the minimization of deficit, (b) the maximization of weighted ridership minus deficit, or (c) the maximization of ridership subject to a deficit constraint. Fares and route structures may be constrained if desired. It is also possible to specify all the service and fare variables and use the model only to determine the ridership and calculate the resulting cost of service, revenue, benefit, and deficit. The analyst may consider peak or off-peak, or both peak and off-peak service within the model, setting constraints (such as equal fare) between the two periods. Likewise, express or local service, or both may be considered.

The model consists of nine cases, each optimizing the system given data on what objective is desired, what combination of local or express service during the peak or off-peak period is to be analyzed, and whether service or vehicle loading constraints exist. Thus the data needed for the specification of a case are

- The objective;
- Whether each decision variable is constrained to a preset value, constrained to be equal in

- the peak and off-peak periods, or free to vary; and
- Which combinations of service (express, local) and time periods (peak, off-peak) to analyze.

These data are entered on the OBJECTIVES menu in the program. The preset values (if any) are recorded on the CONSTRAINTS menu.

Data are required of the current transit operations, to establish a base from which to estimate changes in ridership, service, and cost. For a corridor analysis, the following data are needed:

- Current number of routes,
- Current route length,
- Current fare,
- Current number of bus trips,
- Current ridership,
- Current percentage going to and from the CBD (determines relative CBD and non-CBD market potential),
- Current percentage of passengers moving in the peak direction, and
- Current market share for transit into and out of the CBD.

This information is entered on the EXISTING menu.

The analysis requires the user to specify the following data about ridership characteristics and overall market conditions for transit, entered on the MARKET menu:

- Average walking speed;
- Maximum walk distance;
- Average peak and off-peak CBD parking costs;
- Ratio of wait time to headway; and
- Sensitivities of ridership to service and fare; these relate ridership to fare, running time, walk time, and wait time for each service and time period.

Last, the following operating characteristics are required on the OPERATING menu:

- Maximum policy headway;
- Length of the analyzed corridor along typical traveled streets;
- Width of the corridor at its outer edge;
- Number of expressways in the corridor;
- Size of the CBD;
- Average bus operating speed for each service and time period;
- Length, in hours per day, of each time period;
- Fixed costs per day of each time period;
- Operating costs per bus-hour by time period; and
- Maximum number of passengers per bus by service and time period.

The transit system will have almost all of these numbers at hand. The model manual provides curves and defaults to select the market sensitivities, and the CBD market share is obtained from the regional planning agency if not known. Other variables are either known from collected data or can be estimated fairly well from experience. No special data-collection efforts are needed to support this model.

FRACAS calculates 33 different outputs for each service and time period. This information is organized in a two-screen Management Report, which contains the decision variables and the overall financial results, and a two-screen Technical Report, which contains derived performance and productivity data. The analyst can study these screens freely--it is easy to return to a screen that has already been viewed. The outputs provided are given in Table 1.

TABLE 1 FRACAS Outputs

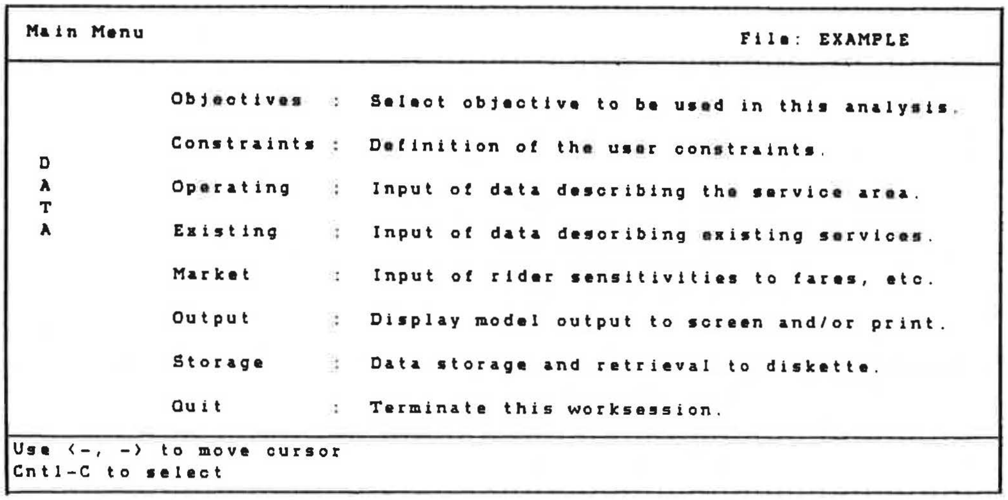
Management Report	Technical Report
Service and Fare:	Performance Statistics:
o Number of Routes	o Bus-Miles
o Average Route Length	o Bus-Hours
o Average Headway	o Number of Bus-Trips
o Average Fare	o Number of Buses
	o Passengers Per Bus-Mile
Overall Impacts:	o Passenger-Miles
o Load Per Bus	o Passenger-Miles Per Bus-Mile
o Mode Share (CBD)	o Cost Per Passenger
	o Revenue Per Passenger
Daily Impacts:	o Deficit Per Passenger
o Cost	o Benefit Per Passenger
o Revenue	o Operating Cost
o Deficit	o Fixed Cost
o User Benefit	o Revenue/Cost Ratio
o Ridership	o Average Passenger Travel Time
	o Average Passenger Walk Time
Annual Impacts:	o Average Passenger Wait Time
o Cost	
o Revenue	
o Deficit	
o User Benefit	
o Ridership	

In response to the question posed at the beginning of this section, FRACAS operates with a relatively large set of decision variables, which is appropriate for a strategic planning function. Transit systems do consider strategic issues such as route consolidation, differential pricing, express service, and use of articulated buses, and FRACAS is designed to perform these analyses. FRACAS does this at a relatively low level of data, not requiring trip tables, networks, on-off counts, or other specialized data collection. The data on which strategic planning is based must be current and easy to maintain, so FRACAS relies on data that should be available in all organizations for basic planning and management functions. By not incorporating detailed data, however, FRACAS gives up the ability to look at most "fine-tuning" issues. FRACAS can be used at a single-route level for general headway and fare design issues, but it cannot prepare schedules. Likewise, at the corridor level, it can indicate the best number of routes to operate, but it is up to the analyst to specify the detailed routing. Key assumptions and limitations of FRACAS are discussed in a later section.

USING FRACAS

When FRACAS starts, the analyst is presented with the MAIN menu (Figure 1). From the MAIN menu, one can select the OBJECTIVES menu, any of the data menus (CONSTRAINTS, AREA, EXISTING, MARKET), the STORAGE page, or the OUTPUT routine. Each will return to the MAIN menu on termination except QUIT, which ends the program.

The STORAGE page gives the analyst the ability to store the information on each of the interactive screens in one named file. With this feature, all the screens can be reset to the values of a previous session that was stored. When the STORAGE page is selected, a screen appears with a menu of storage options and a catalog of all the files currently on disk. This catalog is kept current through all stor-



```
Main Menu                                             File: EXAMPLE

              Objectives   :  Select objective to be used in this analysis.

              Constraints  :  Definition of the user constraints.
D
A             Operating    :  Input of data describing the service area.
T
A             Existing     :  Input of data describing existing services.

              Market       :  Input of rider sensitivities to fares, etc.

              Output       :  Display model output to screen and/or print.

              Storage      :  Data storage and retrieval to diskette.

              Quit         :  Terminate this worksession.

Use <-, -> to move cursor
Cntl-C to select
```

FIGURE 1 MAIN menu.

age and retrieval activity. The options available to the analyst include storing, replacing, loading, and deleting a file, plus printing a list of the data sets on disk. The disk drive to be used for storage and retrieval of data can be specified for the convenience of FRACAS users with more than two floppy drives or a hard disk.

Selecting OUTPUT from the MAIN menu will cause about 90 sec of activity from the computer, ending with the first page of the Management Report being displayed. Using the arrow keys, the user can look through all four pages of output, returning to pages that have already been viewed if desired.

The last option on the MAIN menu is the QUIT option. This option brings FRACAS to an orderly halt.

FRACAS thus operates with six interactive screens. Each screen displays a related body of data or choices that can be entered, modified, or verified by the user. The computer model verifies all data for completeness and correctness before computing any results. Although most errors are detected when the analyst "accepts" a screen, some error-checking requires data across several accepted screens--this checking is done before FRACAS processes the input data. Any errors or omissions detected will cause the program to temporarily return to the affected screen and position the cursor on the problem. A message will be displayed at the bottom of the screen.

Each location to which the cursor moves on the OBJECTIVES menu and the four data menus is a data entry location. For a typical run, the system may need about 50 pieces of information in the data entry locations. When analyzing a variation on a previous run, the user may only need to modify a few values. Data are entered only for items that are used in the analysis. For example, when a peak-period analysis is being done, all off-peak values may be left blank. No zeros or other numbers need be entered.

There is also a "help" facility in FRACAS, which will display a full screen of information for any data item on the five screens containing input data. The help screen will describe the name, type, decimal places, and range of the data value, and give a prose description of the variable.

Running FRACAS is straightforward: the user pages through the interactive screens and inputs the data needed. When finished, the OUTPUT selection is made and the results are displayed. Any information available on any screen can be printed at any time. Any data in the work space can be stored under a unique name at any time.

FRACAS STRUCTURE AND CODING

The first decision to be made in implementing the FRACAS software specification was to choose a microcomputer for FRACAS. Because the program would be relatively large (more than 4,000 lines), there was a temptation to use a powerful machine. However, there were other considerations.

Costs to the end user can be minimized by implementing the system on a small and inexpensive machine, such as the Apple II. The Apple II is likely to be a machine that is often available in transit agencies. For these reasons, the Apple II was chosen as the hardware for FRACAS, even though FRACAS could have been coded more quickly and would run faster on a larger machine.

The second decision to be made concerned the language to use for program development. The two languages that are currently popular with the Apple II are Pascal and Basic. Pascal is a version of University of California, San Diego (UCSD) Pascal. UMTA suggests Pascal as an appropriate language for microcomputers, and the UTPS Screen Handler, on which FRACAS' interactive screens are based, will operate only with software written in Pascal. Apple Pascal, version 1.1, was chosen for FRACAS.

The number of columns available on the screen will obviously affect the amount of information that can be put on one screen and consequently the ease of use of the system. Because both the Pascal system and the UTPS Screen Handler support the addition of hardware to the Apple II that expands the number of displayed columns from 40 to 80, an 80-column card was also specified as part of the hardware package that runs FRACAS. The Videx Videoterm was used in developing FRACAS because it is one of the most common 80-column boards available and would be most likely to be part of existing equipment belonging to transit operators. FRACAS also makes use of the simple, nonstandard line graphics available to the Videx board.

The FRACAS menu screens use a software product called the UTPS Screen Handler. The UTPS Screen Handler is both a set of utilities and a library of procedures for the easy implementation of interactive screens and menus. All of the interactive screens except the REPORT screens were designed with

Screen Handler utilities and operate by calling the Screen Handler procedures. They are internal to FRACAS and transparent to the user.

The FRACAS system is divided into four programs responsible for the input menus, calculations, and output reporting. FRACAS passes control from program to program internally, storing any needed data on disk.

The first program, SYSTEM.STARTUP, is only run when the system is turned on. This program displays the title and calls the input program, FRACAS. The input program handles the interactive input screens, runs the STORAGE page, checks the input data, and writes it on disk before chaining to the output program (OUTPUT). The output program reads the input data from disk, calculates the output variables, and writes the output data to disk before chaining to the reporting program (REPORT). This program reads the output data from disk and displays it on the screen. The reporting program chains back to the input program. This overall structure is shown in Figure 2. It is the need for chaining among programs and for storing intermediate data on disk that accounts for most of the execution time of the FRACAS system. The actual computation time is quite small and if FRACAS were implemented on a larger and more expensive microcomputer, it would run considerably faster. These trade-offs are difficult to assess in system development; experience will show whether the slower, cheaper Apple II implementation is acceptable or whether a faster, more expensive machine would have been better.

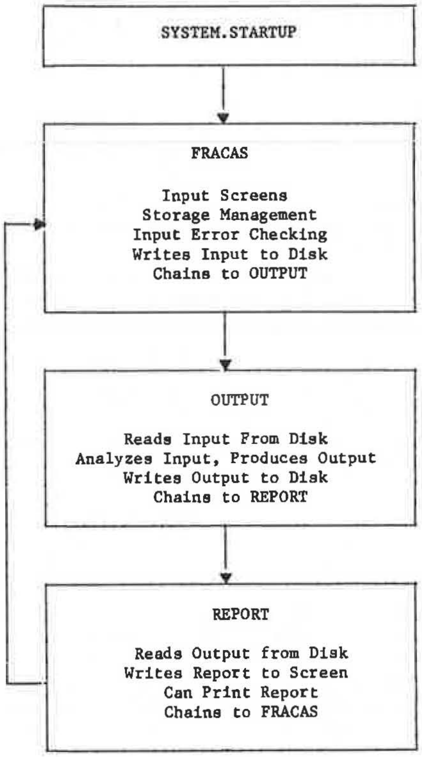


FIGURE 2 Program tasks.

EXAMPLE RUN

In this section, a step-by-step example of the FRACAS model is run. After turning on the system, the user is presented with a title page, automatically followed by the MAIN menu. The MAIN menu contains no data; it is used solely for the selection of the other screens. In this session, the objective screen and the four data screens will be selected and used, and the output of the model will be examined.

MAIN Menu

As shown in Figure 1, the MAIN menu displays the screens and options available in FRACAS, which are selected by moving the cursor to the desired option using the arrow keys on the keyboard and pressing the "accept" key, or "control" C. The cursor can also be made to move up to the work file name. This allows the user to change the name of the file at any time. In this example, the OBJECTIVES menu, which is then displayed on the screen, is selected.

OBJECTIVES Screen

The instructions at the bottom of Figure 3 indicate that the arrow keys will move the cursor; the ESCAPE key will return the user to the MAIN menu; Cntl-P will print the screen; and Cntl-C will "accept" data. Accepting data means that the data on the screen are accepted by the user for storage in the work space. Both ESCAPE and Cntl-C will return the user to the MAIN menu, but only Cntl-C will put the entered data into memory. Thus ESCAPE can be used to leave a menu if users get into trouble changing data that they did not intend to change. The data that were shown when the screen was started will be left in memory.

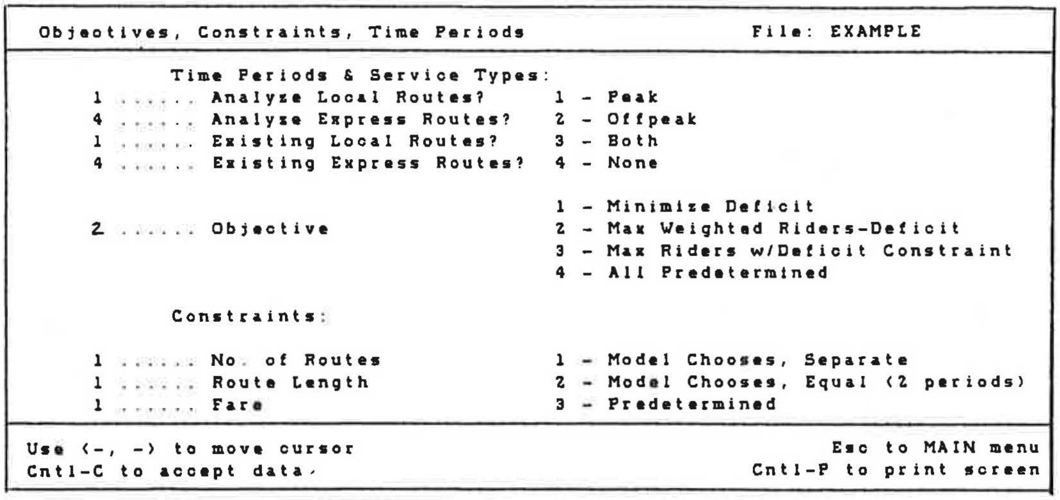
The cursor starts on the position asking "Analyze local service?" This prompt is requesting that the user enter the periods of local service that should be analyzed with this run. In this example, only examining peak-period local service is of interest, so "1" is selected for this first data entry location. The cursor automatically advances to the next position. Because no express service fits into the plans for analysis, "4" is selected here.

It is also necessary to indicate what services are currently being operated. Data describing these services will be entered at a later point and used in the analysis. For this reason, existing data are required in the same time periods (peak or off-peak) as the service or services to be examined although, for example, peak express service can be analyzed even if only local service exists in the peak currently. In this example, there is both peak and off-peak local service already existing, so "3" is entered for the third question. There is no existing express service, so "4" is entered for the fourth question.

Next Objective 2 is chosen from the four possibilities. In this objective, an additional (or lost) rider has a value to the transit operator above and beyond the fare paid. A value of $0.50 will be set on the CONSTRAINTS page to reflect the judgment that the region would be willing to support up to a $0.50 per rider extra deficit for new patronage. The sensitivity to this number can be tested by repeating the analysis with several different values per rider.

The other options for the objective include minimizing the deficit (Objective 1) or maximizing the ridership within a user-specified deficit limit (Objective 3). This deficit limit is entered on the CONSTRAINTS page. By selecting Objective 4, all of the service and fare variables could be specified and the system would report performance data on the design.

The constraints for the output variables are then specified. Because it is desired that the model choose all of the variables, a "1" is entered for



```
Objectives, Constraints, Time Periods                    File: EXAMPLE

              Time Periods & Service Types:
     1 ...... Analyze Local Routes?      1 - Peak
     4 ...... Analyze Express Routes?    2 - Offpeak
     1 ...... Existing Local Routes?     3 - Both
     4 ...... Existing Express Routes?   4 - None

                                         1 - Minimize Deficit
     2 ...... Objective                  2 - Max Weighted Riders-Deficit
                                         3 - Max Riders w/Deficit Constraint
                                         4 - All Predetermined

              Constraints:

     1 ...... No. of Routes              1 - Model Chooses, Separate
     1 ...... Route Length               2 - Model Chooses, Equal (2 periods)
     1 ...... Fare                       3 - Predetermined

Use <-, -> to move cursor                               Esc to MAIN menu
Cntl-C to accept data.                            Cntl-P to print screen
```

FIGURE 3 Example OBJECTIVES screen.

these data. In this case, "1" and "2" are equivalent. If both peak and off-peak service were being looked at, choosing "2" for a variable would constrain the model to pick one value for that variable that worked best for both periods. A variable can be prespecified by entering a "3" here. In this case, the value of that variable would also be entered on the CONSTRAINTS page.

The screen is now finished and can be accepted by pressing Cntl-C. From the MAIN menu, the next option is selected--the CONSTRAINTS screen. FRACAS anticipates that the user will go to the next screen and moves the cursor down one step on the MAIN menu.

CONSTRAINTS Screen

This screen shown in Figure 4 is similar to the previous screen, but more complicated; as many as 25 data items may be specified here, and the screen accepts multidigit real numbers.

Not all of the data that can be entered on this screen are needed for this run, although the user may put in additional information so that it will be there if needed for future analysis. To determine what is needed, the user needs to look at the line on the screen labeled "used this run."

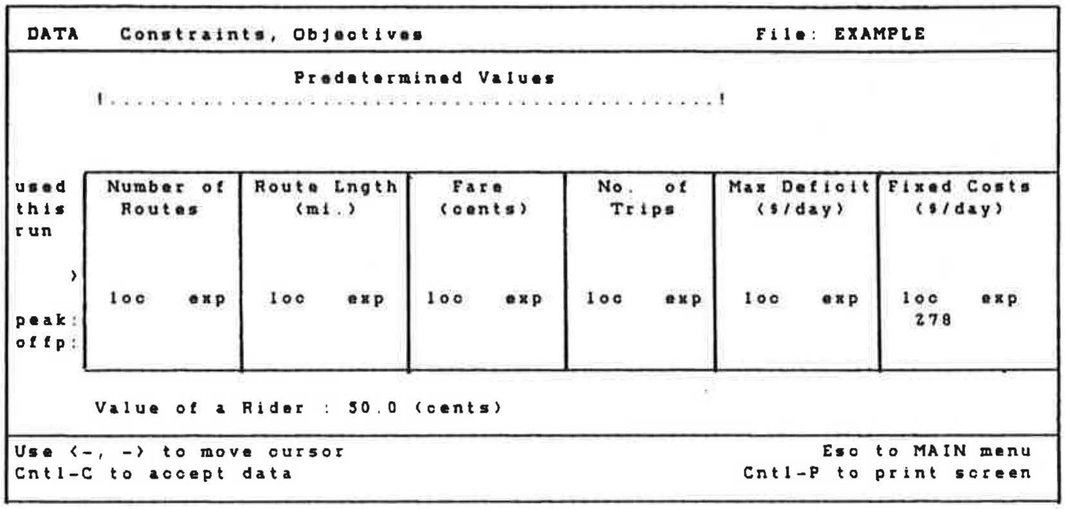
Data are needed in the boxes that have a bar on this line. Data are needed for the value of rider if there is a bar above it. Notice that for this run data need to be entered only for "Fixed Costs" and for "Value of Rider." In fact, data need to be entered only for the peak-local cell for fixed costs, because this is all that is being analyzed. If the user wishes to prespecify some of the output variables, that can be done here under "Predetermined Values."

Values entered are "278" for fixed costs and "50" for the value of the rider; then Cntl-C is pressed to return to the MAIN menu and Cntl-C is pressed again to move on to the next menu.

OPERATING Screen

The operating data reflect many of the characteristics of the area and the transit system. Some of the area characteristics are described in greater depth in Kocur (1) and care must be taken in setting their values in actual analyses. They are discussed only briefly here.

The area dimensions must be entered, so the length of the corridor is selected as 8 miles (Figures 5 and 6), beyond which there is little develop-



```
DATA   Constraints, Objectives                    File: EXAMPLE

                   Predetermined Values
     !..........................................!

used  Number of  Route Lngth   Fare      No. of   Max Deficit  Fixed Costs
this   Routes      (mi.)      (cents)    Trips     ($/day)      ($/day)
run

    >
      loc  exp   loc  exp    loc  exp   loc  exp   loc  exp    loc  exp
peak:                                                          278
offp:

      Value of a Rider : 50.0 (cents)

Use <-, -> to move cursor                          Esc to MAIN menu
Cntl-C to accept data                          Cntl-P to print screen
```

FIGURE 4 Example CONSTRAINTS screen.

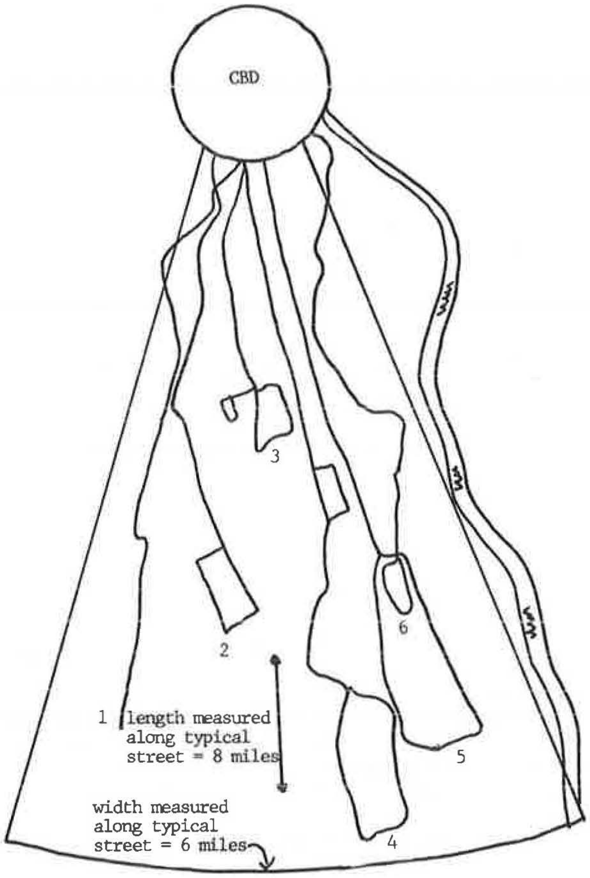


FIGURE 5 Map of example area.

ment. Maximum width of the corridor at its outer edge is about 6 miles. The number of expressways in the corridor is 1, although this number is used only in express analysis. The length of the CBD is also used only in express analysis to determine the time spent in CBD distribution. The distribution run for expresses would be 0.5 miles. The number of analysis days per year is used only to convert from daily to annual statistics.

The expected ratio of total bus-hours to in-service hours is estimated by the user. Total bus-hours include layovers, deadhead time, and other nonservice time. In-service hours are those the bus is actually in revenue service operating along the route. A ratio of 1.4 is used in this example to estimate total bus-hours and the bus fleet size.

The bus operating cost varies between peak and off-peak periods. Although the model will accept a uniform cost for peak and off-peak service, it is generally better to estimate the two separately. For the peak period, the cost of a peak-only bus, computed as the average cost per in-service hour over trippers, split shifts, and other driver assignments for peak-only runs is used. In off-peak periods, the cost per in-service hour of a vehicle operated all day is used. In both periods, costs are strictly for in-service time, not including layover or deadhead times. A peak cost of $36 per hour is used here. The off-peak cost is not needed in the example.

The length of the analysis periods is the number of hours each day with peak or off-peak service. For the example, there are 4 hr of peak service each day.

The maximum load per bus reflects the equipment type and the loading standards of the property. Different equipment types can be reflected by varying the values of the maximum load per bus, cost per bus-hour, and speed. Because maximum load is a constraint on the average load in a peak or off-peak period at the peak load point, it should be lower than the ultimate capacity of the vehicle. Forty passengers per bus are used in this example.

For local service, the average bus speed includes delays for boarding and alighting. The speed chosen for this example is 12 mph in the peak.

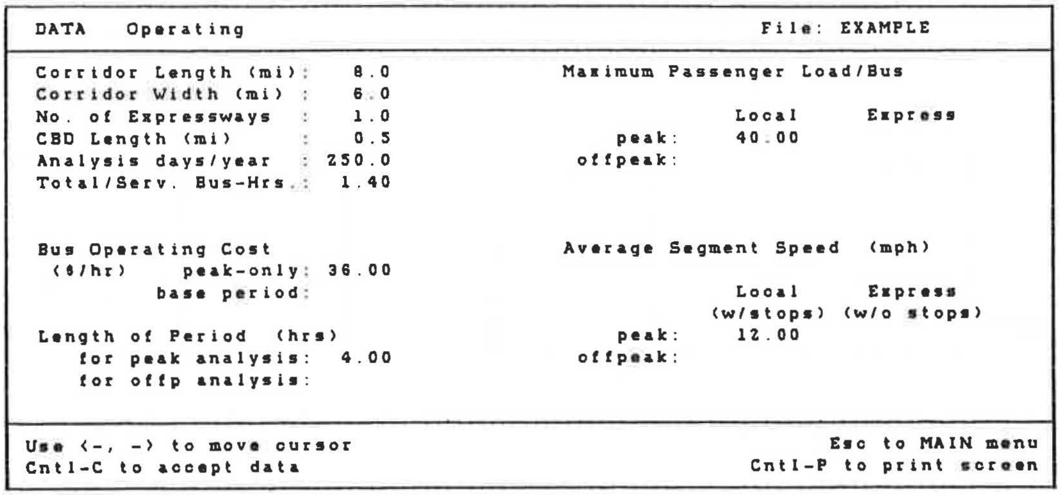
EXISTING Screen

This screen (Figure 7) allows the user to enter data for eight variables describing existing service.

The number of routes, six, is determined from the map. The average route length is found by adding the total length of all routes counted and dividing by the number of routes. The average route length calculation gives 7 miles.

The average fare should be estimated for each of the service and time periods for which data are required. If the average fare paid in each service and time period is not known, the nominal adult fare should be used. The fare for this example is $0.70.

The current number of bus trips in the peak direction is calculated from the current schedules.



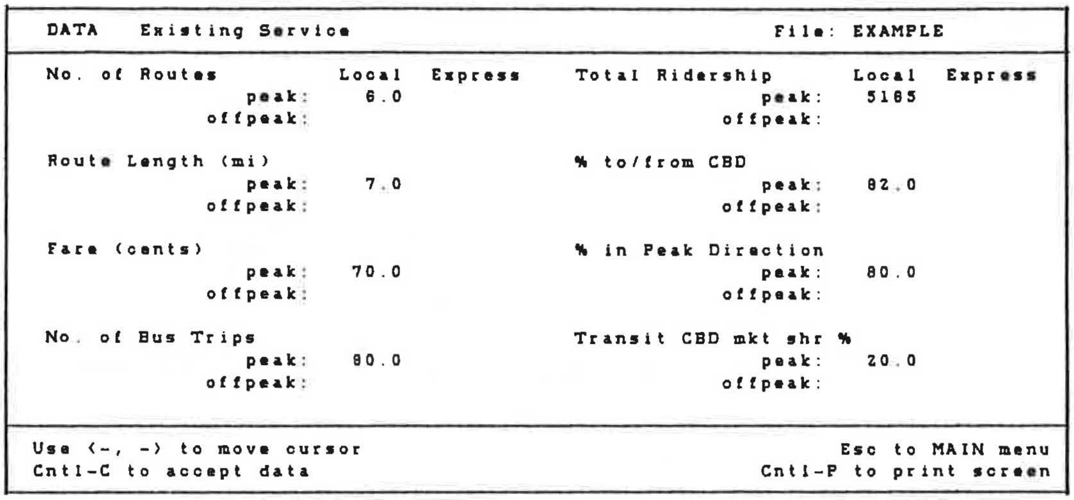
```
DATA    Operating                                  File: EXAMPLE

Corridor Length (mi):    8.0         Maximum Passenger Load/Bus
Corridor Width (mi) :    6.0
No. of Expressways  :    1.0                       Local      Express
CBD Length (mi)     :    0.5                peak:  40.00
Analysis days/year  :  250.0             offpeak:
Total/Serv. Bus-Hrs.:   1.40


Bus Operating Cost                   Average Segment Speed  (mph)
 ($/hr)     peak-only: 36.00
          base period:                                 Local      Express
                                                    (w/stops)  (w/o stops)
Length of Period  (hrs)                     peak:  12.00
   for peak analysis:  4.00              offpeak:
   for offp analysis:

Use (-, -) to move cursor                               Esc to MAIN menu
Cntl-C to accept data                               Cntl-P to print screen
```

FIGURE 6 Example OPERATING screen.



```
DATA    Existing Service                                 File: EXAMPLE

No. of Routes           Local  Express    Total Ridership       Local  Express
                peak:    6.0                              peak:  5165
             offpeak:                                  offpeak:

Route Length (mi)                         % to/from CBD
                peak:    7.0                              peak:  82.0
             offpeak:                                  offpeak:

Fare (cents)                              % in Peak Direction
                peak:   70.0                              peak:  80.0
             offpeak:                                  offpeak:

No. of Bus Trips                          Transit CBD mkt shr %
                peak:   80.0                              peak:  20.0
             offpeak:                                  offpeak:

Use (-, -) to move cursor                                  Esc to MAIN menu
Cntl-C to accept data                                 Cntl-P to print screen
```

FIGURE 7 Example EXISTING screen.

Short-turns are counted as fractional values. In this example, the number of bus trips over the six routes is 90. This is the number of inbound trips in the morning peak plus the number of outbound trips in the evening peak.

The total ridership over all routes is found from revenue or passenger count data. Ridership for the example is 5,165 in both directions over the two peaks. The fraction of current transit riders bound to or from the CBD, including transfers in the CBD, is estimated from ridership counts or from experience. In this case, the value is 0.80.

The current mode share of all CBD trips captured by transit is generally obtainable by dividing transit ridership to the CBD by the total person trips to and from the CBD. The total flow of persons to and from the CBD is usually obtainable from regional transit planning agencies, state departments of transportation, or downtown associations. For this example, 0.20 is used.

MARKET Screen

These data (Figure 8) pertain to the market characteristics of the geographic area. Along with the EXISTING data, these data tend not to change much after they have been set.

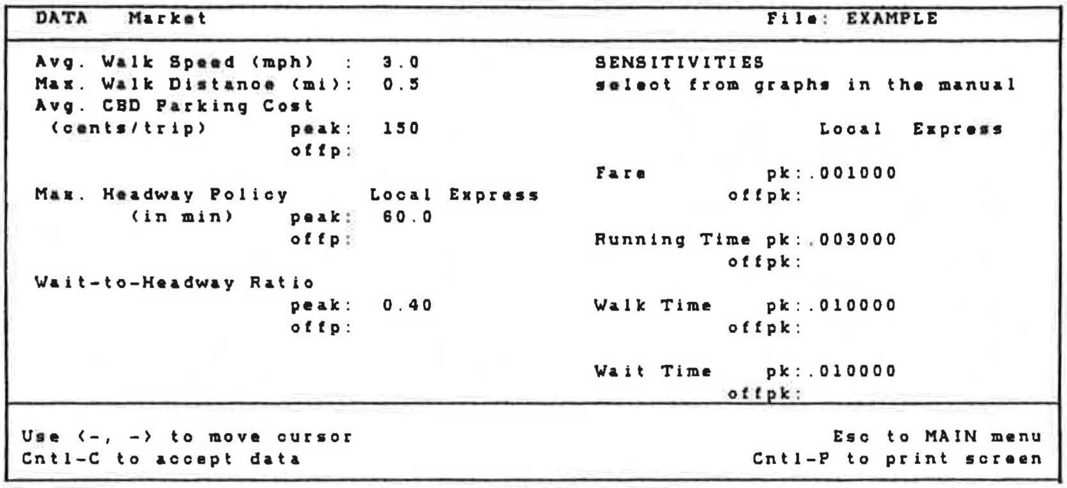
The average walk speed is generally considered to be 3 mph; this is what is used here. The maximum distance beyond which no persons are willing to walk is based on operator experience and judgment. A value of 0.5 mile is used in the example.

The average CBD parking cost is entered for both peak and off-peak users. A peak CBD parking cost of $1.50 is used here.

The maximum policy headway is set by the analyst on the basis of either formal or informal service standards. These standards will not typically be binding in the peak period. Maximum policy headway is 60 min in this example.

The standard value for the ratio of average passenger wait time to route headway is 0.5. It can be greater than 0.5 for poorly kept, short headways and less than 0.5 for well-kept long headways. Because good schedule adherence is expected in the example, this ratio is set at 0.4.

The market sensitivities in the second column are set by examining the graphs shown in Figure 9. Typically, the market coefficients will differ between peak and off-peak period travel and may differ between local and express traffic. Choose a coefficient that represents a curve in the figure that is believed to represent the true changes in ridership that would occur in the corridor being studied. The user may interpolate between the curves if neces-



```
DATA   Market                                         File: EXAMPLE

Avg. Walk Speed (mph)   :  3.0               SENSITIVITIES
Max. Walk Distance (mi):  0.5               select from graphs in the manual
Avg. CBD Parking Cost
 (cents/trip)       peak:  150                             Local  Express
                    offp:
                                             Fare         pk:.001000
Max. Headway Policy     Local Express                  offpk:
       (in min)     peak:  60.0
                    offp:                    Running Time pk:.003000
                                                       offpk:
Wait-to-Headway Ratio
                    peak:  0.40              Walk Time    pk:.010000
                    offp:                              offpk:

                                             Wait Time    pk:.010000
                                                       offpk:

Use (-, -) to move cursor                                  Esc to MAIN menu
Cntl-C to accept data                                 Cntl-P to print screen
```

FIGURE 8 Example MARKET screen.

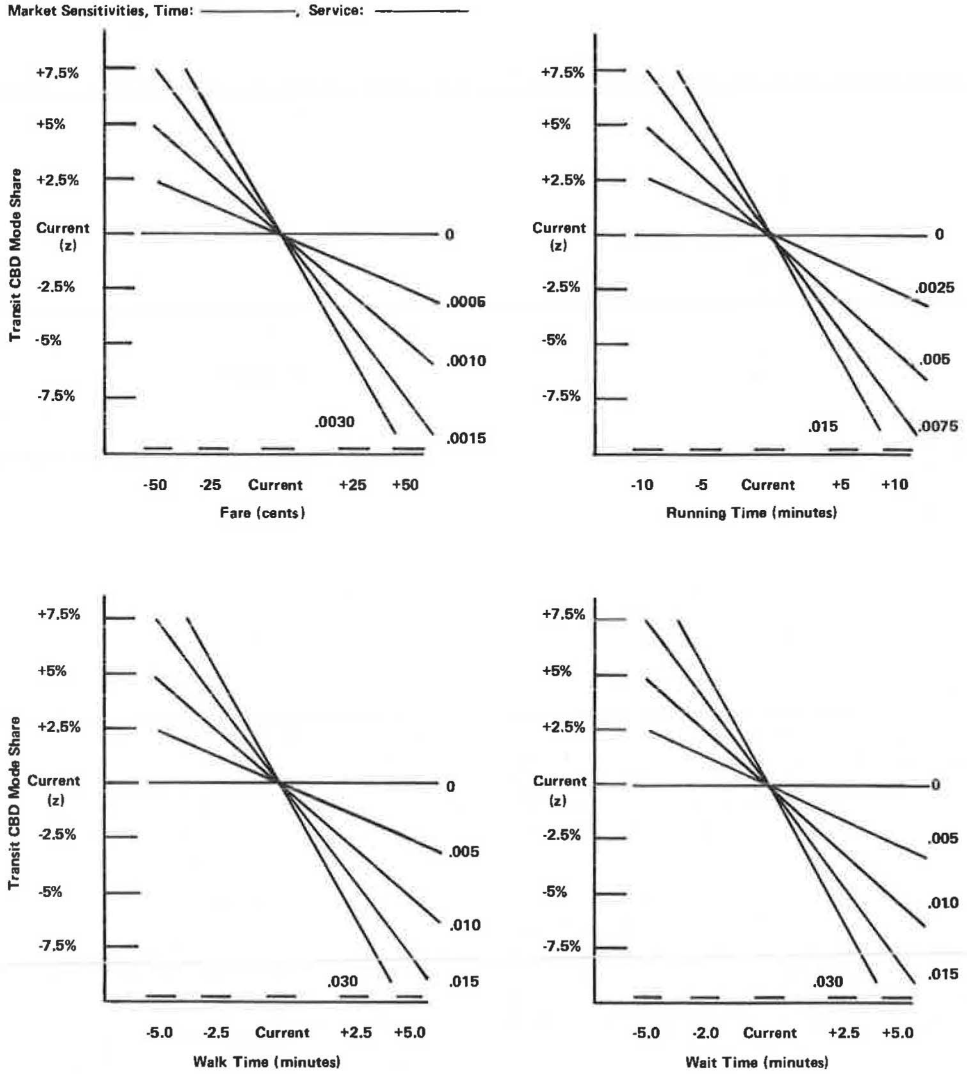


FIGURE 9 Market sensitivity curves.

sary. Alternatively, the demand coefficients can be found from the corresponding elasticities if known. Values are entered from the curves, as shown, and the screen is accepted. OUTPUT is then selected from the MAIN menu because all input is complete.

Output

When the calculation messages have finished, the report screen will show the results. Notice the changes that were made in the system (Table 2). The fare has increased from $0.70 to about $1.00; headway is reduced from 16 to 12 min; the number of routes comes down from 6 to 4.

These optimal values are indicative of directions that produce ridership increase, deficit decrease, or productivity increase. In this example, the value per extra rider is rather low ($0.50), so service is expanded only until the deficit for the last rider reaches $0.50. Because the deficit per rider increases as marginal patronage is sought, most riders cost the system less than $0.50 deficit. With a $0.70 current fare, this means that a high revenue-to-cost ratio is implicitly required. The model suggests the best way to achieve this. Note that headways actually improve, although routes are cut and fares increase sharply. This strategy differs from those many systems may follow. If the user wishes to alter portions of the solution, they can be constrained by returning to the OBJECTIVES screen and setting the variables as predetermined and then moving to the CONSTRAINTS page to specify a value. For example, the fare could be locked in at $0.80 if that was the maximum value the operator felt could be implemented. The model can be rerun, and the new results obtained. Using this iterative process, the user of FRACAS should be able to achieve a better intuitive understanding of the transit system than was previously possible.

If the operator found all the changes in this run satisfactory (which is not expected for a first run, but was assumed for sake of example), the design and impacts of the best service to achieve the system's goals are set. In this example, approximately four routes at 12- to 13-min average headways will be operated; a fare of approximately $1.00 will be charged; the routes will be run out about 7 miles in the corridor. The specific design of the four routes is left to the analyst and his local knowledge; this is a hard task for a computer. A possible revised route pattern is shown in Figure 10. It uses four routes instead of the current six, and they are slightly longer. They are spaced as evenly as pos-

TABLE 2 Output Report

```
                          File: EXAMPLE

                                        PEAK                 OFFPEAK          TOTAL
                                  Local     Express     Local     Express

Service
& Fares:     No. of Routes:        3.81      0.00        0.00      0.00
         Route Length (mi):        7.14      0.00        0.00      0.00
        Avg. Headway (min):       12.45      0.00        0.00      0.00
        Avg. Fare (cents):       102.81      0.00        0.00      0.00

Impacts:      Load Per Bus:       40.00      0.00        0.00      0.00     40.00
          Mode Share (CBD):        0.17      0.00        0.00      0.00      0.17


Daily
Impacts:           Cost($):     3421.65      0.00        0.00      0.00   3421.65
                Revenue($):     4332.29      0.00        0.00      0.00   4332.29
                Deficit($):     -910.64      0.00        0.00      0.00   -910.64
           User Benefit($):     2890.49      0.00        0.00      0.00   2890.49
                Ridership:      4214.08      0.00        0.00      0.00   4214.08

Annual
Impacts:           Cost($):      855.41      0.00        0.00      0.00    855.41
(000's)         Revenue($):     1083.07      0.00        0.00      0.00   1083.07
                Deficit($):     -227.66      0.00        0.00      0.00   -227.66
           User Benefit($):      722.62      0.00        0.00      0.00    722.62
                Ridership:      1053.52      0.00        0.00      0.00   1053.52

Daily
Statistics:     Bus-Miles:      1047.88      0.00        0.00      0.00   1047.88
                Bus-Hours:       122.25      0.00        0.00      0.00    122.25
            No. Bus Trips:        73.43      0.00        0.00      0.00     73.43
                No. Buses:        30.56      0.00        0.00      0.00     30.56

          Psgr./Bus-Mile:          4.02      0.00        0.00      0.00      4.02
              Psgr.-Miles:     15034.3       0.00        0.00      0.00  15034.3
    Psgr.-Mile/Bus-Mile:          14.35      0.00        0.00      0.00     14.35

   Avg. Travel Time (min):        17.84      0.00        0.00      0.00     17.84
     Avg. Walk Time (min):         4.98      0.00        0.00      0.00      4.98
     Avg. Wait Time (min):         4.98      0.00        0.00      0.00      4.98

Daily:
(in $)      Cost/Passenger:        0.81      0.00        0.00      0.00      0.81
         Revenue/Passenger:        1.03      0.00        0.00      0.00      1.03
         Deficit/Passenger:       -0.22      0.00        0.00      0.00     -0.22
         Benefit/Passenger:        0.69      0.00        0.00      0.00      0.69

          Operating Cost:       3143.65      0.00        0.00      0.00   3143.65
              Fixed Cost:        278.00      0.00        0.00      0.00    278.00


     Ratio Revenue/Cost:          1.27      0.00        0.00      0.00      1.27
```

sible and operate over existing route segments whenever possible.

There are some major implementation issues in making such a routing change, and these have to be weighed carefully. However, the model does point out that even under the objective used in this example, which places tight financial bounds on the operator, headway increases are self-defeating. Obviously, fares go up; but the key is to increase walk times a little, by adjusting route structure, instead of increasing wait times a lot through headway increases. These conclusions are dependent on the market sensitivities of wait and walk time, which should be varied to examine the robustness of the result.

Under objectives that place more value on ridership or allow larger deficits, route restructuring is likely to be more acceptable. In such cases, the fares will be at or even below current levels; headways will improve; travel time will improve (due to elimination of loops and probably more widely spaced stops, treated elsewhere in the model); but walk times will increase. Thus the operator can argue that the disadvantage of slightly longer walk distances is more than offset by the other improvements. Express service can also aid in this argument.

The "profit" of $911 earned in the example is only a peak-period surplus; off-peak losses will more than offset it. The ridership of 4,214 is a 19 percent decrease from current ridership. Combined walk and wait times are almost the same in the current and redesigned systems, although the mix is different: wait times decrease from 6.4 to 5 min, and average walk times increase from 3.8 to 5 min. The fare increases from $0.70 to about $1.00. With a fare elasticity of about 0.35, the expected ridership decrease is about 0.35 x 30/70 or 15 percent. A slight further decrease is caused by the slightly shorter route lengths and correspondingly smaller service area. Thus the model results "check" against all the parameters.

This would not be the only model run for the corridor, of course. It could be rerun setting the number of routes to exactly four, or the fare could be

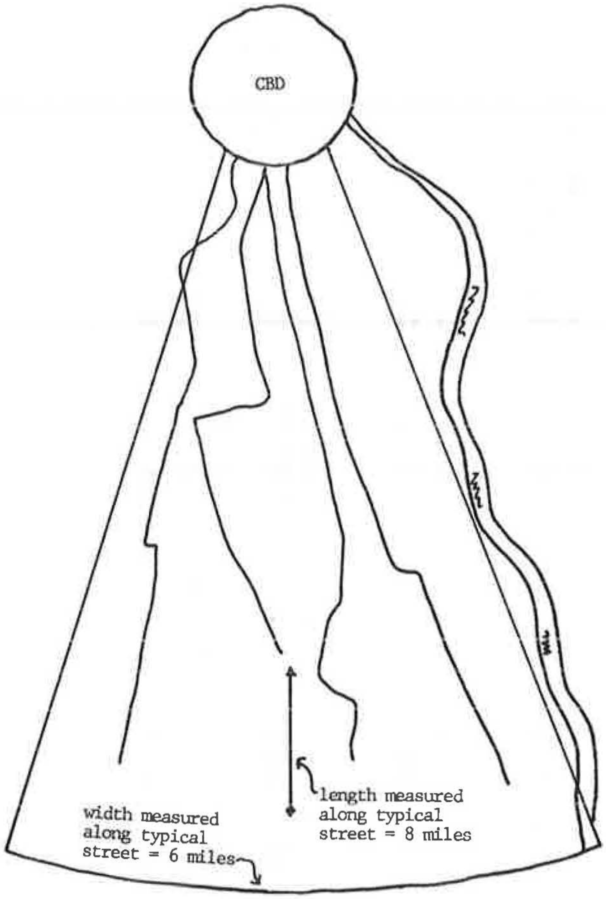


FIGURE 10 Revised route pattern.

constrained to something less than $1.00, and so forth. Express and off-peak services could also be considered, and routes could be examined one by one if they varied greatly in their ridership and operating characteristics. The model is a design and analysis aid, but the analyst must use it creatively to develop good, implementable, strategic options, which always require detailed local knowledge.

ASSUMPTIONS AND LIMITATIONS

Corridor Characteristics

The FRACAS model requires only data that are generally available to or can be estimated by a transit operator. It uses no networks, trip tables, statistical demand models, or other conventional data sources in transportation planning. Nonetheless, it generates acceptable alternatives and evaluates a wide range of impacts. To do this, the model makes assumptions about the difficult-to-measure data items that it does not use.

FRACAS is a so-called "continuous" model that treats each route or corridor as operating in an area of slowly varying population density and operating characteristics. FRACAS assumes that population (and trip) density declines approximately piecewise linearly from the CBD outward.

Route ridership data (from which trip density is inferred) can be entered for two segments if route boardings vary greatly. If boardings follow a relatively smooth, increasing pattern, a single ridership number will produce a good "fit" with the observed boarding pattern.

The model treats the corridor as having fairly continuous development with most of the area occupied. If development is very concentrated with much undeveloped space in between (e.g., a set of small towns with open farmland in between), the model is not appropriate. In urban areas, even if there are clusters of development or concentrations along particular streets, the model is adequate as long as the remaining development is continuous.

The corridor is assumed to have enough through streets to operate the desired number of routes and it is assumed that the rest of the street network is well enough connected to allow users to walk a moderately circuitous path to a bus route. In some suburban areas, this may be a problem. In that case, the bus operating speeds and user walk speeds are reduced to reflect circuity.

Population density is assumed to be the same in different portions of the corridor at the same distance from the CBD. If this is not the case, the corridor-average optimal service levels may not reflect route averages very well (although the corridor summary statistics will still be fairly good estimates in all but the most extreme cases). To deal with this problem, single-route analyses should be done in the corridor, or the corridor can be broken into more uniform parts.

The route structure suggested by the model is laid out by the analyst. The model assumes equally spaced routes in making its assessments, but moderate departures from equal spacing have little effect. The analyst should choose the routing for the selected number of routes that is believed to be best. If the route spacing is extremely nonuniform, rerun the model at a single-route level to confirm the results.

Transit Market

The model selects whether the primary market for transit is CBD trips only or both CBD and non-CBD trips. It does this by comparing the value of objective functions that can be achieved in either case. Three possibilities emerge:

1. The service is designed and priced strictly with the CBD travel market in mind; non-CBD transit trips essentially are not made. This occurs particularly if high fares are set, which CBD users will pay because of high parking costs, but non-CBD travelers will not pay.
2. The service is again designed and priced for the CBD travel market, but residual non-CBD transit travel remains. Here the non-CBD market is not large enough to affect the design, but the pricing and service are still attractive to some non-CBD travelers.
3. The service is designed and priced for both CBD and non-CBD travel, because both are potentially significant. In this instance, the fares, headways, and route structure are a compromise for both markets.

The non-CBD travel included in the model is within-corridor travel along the radial routes plus transfers through the CBD. This version of FRACAS treats radial routes only. (An extension to crosstown and grid routes is being prepared.) Specific service to non-CBD destinations within a corridor cannot be treated except as a deviation of the CBD-bound routes passing by it. A diagonal or crosstown route cannot be treated. Transfer trips through the CBD are treated as CBD trips for simplicity.

To predict ridership for new options, the model uses an internal linear demand function based on the coefficients input by the analyst. The model predicts changes from the base ridership using these coefficients, instead of generating an estimate from scratch. It is similar to an elasticity or (logit) pivot point approach, except that it uses the linear approximation because it is easier to compute. (As in logit pivot point, the elasticity in the linear model is not constant but varies with market share and service level.) All transit users are assumed to be choice users. They may not all have driving as a choice, but they can walk, get a ride, move, or make some other change if transit service changes. Travelers are assumed to react to travel time, walk time, wait time, fare for transit, and automobile parking cost (for CBD travelers). The times and costs of non-transit options are implicit in the model and are assumed not to change. Travelers are assumed to use the transit route nearest their home.

Operating Characteristics

The model treats costs on a per minute (or hour) basis only, because labor is the most important component. Two cost levels are used: those for buses that operate in the peak only (split duties or trippers, or both) and those that operate all day. Detailed timing and scheduling issues are not considered, such as whether vehicles on long routes can make two round trips in a peak period. For example, substituting express for local service on a long route will decrease running time and cost in the model, while it may or may not eliminate vehicles or drivers in the actual schedule. These issues are beyond the scope of FRACAS.

The variation of passenger loadings within a peak or off-peak period is treated only indirectly in FRACAS. The bus capacity constraint is applied to the average load over the period, as is done by many transit properties today. To consider variations in passenger flow more explicitly, the period must be subdivided into shorter time periods and the model rerun for each (with constrained route structure and fare) to find the best headway and meet short-term demand peaks. The trip density (computed from existing ridership), cost, speed, and loading standard can vary for each period.

Use of Approximations

The number of routes that emerges as the optimum from FRACAS is not an integer. Either round up or down (or try both) and rerun the model with predetermined routes to find an integer answer. The best number of routes will always be the next smallest or next largest integer from the initial solution. Generally, either one will be quite good.

The optimal values of all the fare and service variables are found from approximate solutions of complex equations. Occasionally, by playing with the model, the user may be able to improve on the optimal solution given by FRACAS. Usually the improvement will be quite small. The one exception is that the route length calculation does not take fare or route spacing constraints into account. If severe constraints exist, the best route length will generally be somewhat shorter than the model indicates.

These are the major assumptions and limitations of FRACAS. It is a design tool to aid operators in coming up with their own service, routing, and fare plans for specific corridors and routes, as well as a strategic planning model at the systemwide level. Some of the input data are judgment based, and there are approximations and assumptions in the model that may not hold in every case. Its output should not be taken as absolute, but as a guide to local transit decisions. However, FRACAS can generate and evaluate options for a wide range of circumstances and goals in a flexible manner, and it represents a substantial advance in the ability to do transit fare and route analysis.

CONCLUSIONS

An overview of a microcomputer-based strategic planning model for bus transit systems has been presented. The model is entering its field test stage, so no implementation results are yet available. It has the promise of allowing flexible analysis of routing, pricing, vehicle size, express service, and headway options in a user-friendly environment and without the collection of additional data. It operates at a level of detail that is more approximate than most current service planning analyses, which are focused on route-level detail. FRACAS seems most appropriate for strategic planning (and general learning about trade-offs), and it may support certain (though not all) service planning functions well.

ACKNOWLEDGMENT

This work has been supported by the Program of University Research, U.S. Department of Transportation.

REFERENCES

1. G. Kocur. A Unified Approach to Performance Standards and Fare Policies for Urban Transit Systems, Vols. 1-4. Research and Special Projects Administration, U.S. Department of Transportation, May 1983.
2. G. Kocur. An Extended Optimization Model with Variable Demand of Urban Bus Systems. In Management Science and the Delivery of Urban Services, A. Swersey, ed., TIMS Series in the Management Sciences, in press.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Limited-Stop Bus Operations: An Evaluation

JAMES M. ERCOLANO

ABSTRACT

Limited-stop bus services have the capability of serving a ridership demand market between that of regional express and that of local bus operations. Limited-stop bus services in New York City's borough of Manhattan were evaluated by comparing performance characteristics and passenger use to those of local service on the same routes. Random spot-survey results and recent secondary data sources revealed considerable travel time savings, faster average operating speeds, rider preference for limited buses (where available), and attraction levels comparable to those of local bus service. Modest operating cost savings were computed, with stopping frequencies closer to express service being the most economical. Among the types of service-related cost savings cited from employing limited scheduling, annual savings from peak vehicle reductions amount to more than 60 percent of total possible economies expected through using limited bus runs for roughly half the peak period trips on suitable routes. Two sets of bivariate regression models were computed and calibrated to serve as general sketch-planning guides for reviewing routes that may benefit from limited-service implementation. Five warrants explaining what service revisions and performance modifications are essential if limited bus operations are to be feasibly used to cut costs and attract ridership are presented.

With the cooperation and assistance of the New York City Transit Authority and Polytechnic Institute of New York, a data-collection effort was conducted to make a rudimentary, and where feasible a statistically valid, comparison (by route composites) of local and limited bus operating characteristics.

Data derived from random spot surveys included passenger counts and delay durations, frequencies, and causes of stopped time. Previous studies of operating speeds, travel times, peak-period costs, and passenger use were applied to adjust survey results and estimate the impact of a modified or faster limited service (1,2). From these data, a comparative microeconomic (using component cost figures) and macroeconomic analysis using monetary and time costs per route determined the significance of savings and service enhancements expected from peak-period limited bus scheduling.

Because of the greater time savings possible in Manhattan, operating cost estimates were based on the most conservative cost savings, which are generally applicable to cities with lower population and commercial space densities.

DEFINING LIMITED SERVICE

To a lesser extent than are express operations, limited service is designed to serve passenger-stops only at major sites and along major corridors and trip-generation zones. Figure 1 shows how various degrees of limited service can be scheduled.

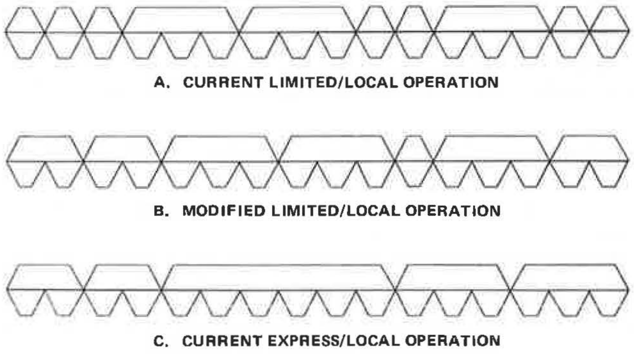


FIGURE 1 Examples of passenger-stop operating strategies.

Using a method of illustrating stopping frequencies applied by Vuchic et al. (3), each horizontal diagram in Figure 1 compares a specific type of bus operation (shown above a one-way route line) to a local bus stopping frequency (shown below each line). Each diagram illustrates a single trip, and each connection point along these diagrams is roughly equivalent to five scheduled and four actual passenger-stops per route segment. Therefore, local-stop, current limited, and modified limited trips represent approximately 75, 50, and 30 scheduled passenger-stops and 60, 40, and 25 actual average passenger-stops per trip.

The top diagram of Figure 1 depicts current limited operations--those peak-period services now in existence on five routes (M-1, 4, 5, 10, and 32) in the borough of Manhattan (4). Because current limiteds make an extensive number of stops in designated route segments, their greater pick-up coverage results in operating characteristics closer to those of local bus scheduling.

The middle diagram shows a modified version of limited service that was recently initiated on one route (M-15) serving the east side of the borough. Further reductions in pick-up coverage permit modified limiteds to approach levels of performance associated with express operations.

Comparative stopping frequencies of express and local service are shown in the bottom diagram. Although express schedules provide higher levels of service and ridership attraction potential, their suburban orientation, longer route distance, and far greater route spacing prohibit their meeting an overwhelming share of nonlocal intracity travel demand.

STUDY FINDINGS

Operating Speeds and Travel Times

A significant increase in surface transit operating speeds causes shorter travel times and reductions in the number of peak vehicles needed, which result in a decrease in annual operating costs and capital spending. An increase in operating speeds can also retain or generate greater ridership per capita for the bus system (5).

On-board surveys revealed the crucial influence of mixed traffic conditions on limited-bus speeds. Observations of route segment performance variations indicated a tendency for limited buses to be from 50 to 100 percent faster than local buses under light traffic and urban highway conditions and 20 to 30 percent faster under moderate traffic and arterial roadway conditions. Both speeds begin to approach parity under heavy traffic and central business district (CBD) conditions.

Figure 2 shows a microanalysis that uses the mean travel times and headways from 15 north-south routes selected for evaluation on the basis of the analytical determination of minimum route distances greater than 5.0 miles to maintain acceptable travel time savings per typical user trip length. This microanalysis shows an average increase in operating speeds of approximately 0.9 mph (6.4 to 7.3 mph) and 1.6 mph (6.4 to 8.0 mph) for current and modified limited bus service, respectively. Higher speeds resulting from stopped time reductions occurred because of declines in passenger-stop frequencies and, to a lesser extent, all other delay causes (6).

A relationship between travel times and route distances was established by calculating the percentage change in trip times from Figure 2 to plot travel times for local, limited, and modified service. Data from the 15 Manhattan bus routes studied were used, and Figure 3 shows a set of linear regression configurations with a correlation of r = 0.89. For each type of stop service, three bivariate regressions were computed for predicting trip times by route lengths. After a steady rise in travel time savings, a point of diminishing returns may be

Average Travel Time = 60(8.9 miles) = 83.4 minutes
of Local Service 6.4 mph

Est. % of Passenger Local = 58 Stops x 14 secs. = 13.5 minutes
Stop Delay Time CLS = 36 Stops x 15 secs. = 9.0 minutes
MLS = 24 Stops x 16 secs. = 6.4 minutes

Current Limited = (13.5) 36 = 8.38 Mod. Limited = (13.5) 24 = 5.59
Delay Time 58 mins. Delay Time 56 mins.

13.5 mins.-8.38 mins.=5.13 mins. 13.5 mins.-5.59 mins.=7.91 mins.

Est. % of Signal Local = 30 Stops x 25 secs. = 12.5 minutes
Stop Delay Time CLS = 22 Stops x 26 secs. = 9.5 minutes
MLS = 16 Stops x 27 secs. = 7.2 minutes

Current Limited = (12.5) 22 = 9.17 Mod. Limited = (12.5) 16 = 6.67
Delay Time 30 mins. Delay Time 30 mins.

12.5 mins.-9.17 mins.=3.33 mins. 12.5 mins-6.67 mins=5.83 mins.

Est. % of Remaining Local = 11 Stops x 20 secs. = 3.7 minutes
Stop Delay Time CLS = 6 Stops x 22 secs. = 2.2 minutes
MLS = 3 Stops x 24 secs. = 1.2 minutes

Current Limited = (3.7) 6 = 2.02 Mod. Limited = (3.7) 3 = 1.01
Delay Time 11 mins. Delay Time 11 mins.

3.7 mins-2.02 mins.=1.7 mins 3.7 mins.-1.01 mins.=2.7 mins.

CURRENT AND MODIFIED LIMITED TIME SAVINGS

	Trip Time	PSD	TSD	OTD		New Trip Time
Current	83.4	- 5.12	+ 3.33	+ 1.7	=	73.2 minutes
Limited		(83.4 - 10.2)				(10.2 mins. Saved/Trip)
Modified	83.4	- 7.91	+ 5.83	+ 2.7	=	67.0 minutes
Limited		(83.4 - 16.4)				(16.4 mins. Saved/Trip)

Current Limited = 60(8.9 miles) = 7.3 mph New Run Time
Travel Speed & 73.2 mins.
Time Savings (20.4 mins. Saved/Run)

Modified Limited = 60(8.9 miles) = 8.0 mph
Travel Speed & 67.0 mins.
Time Savings (32.8 mins. Saved/Run)

FIGURE 2 Speed and delay changes resulting from current 36-stop and modified 24-stop limited bus operation.

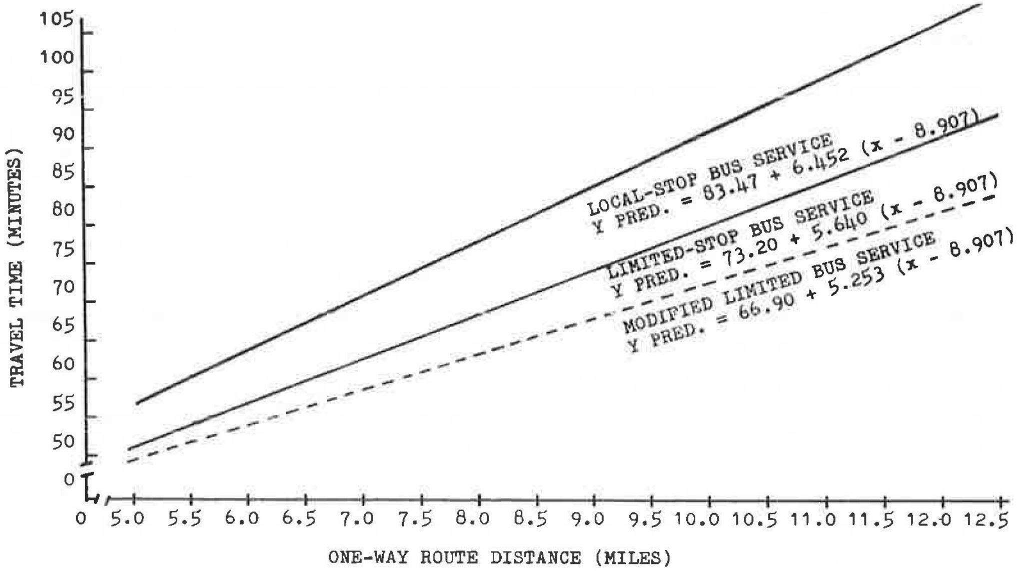


FIGURE 3 Relationship between peak travel times and route distances.

reached for route lengths longer than 9 miles; however, actual time savings are greatest for the longest routes.

Service Costs and Savings

An economic comparison of bus service cost components was conducted to estimate total capital and operating costs, the relative share of total costs each represents, and the amount of savings possible from both current and modified limited bus operations.

With headways, miles traveled, and existing scheduling held constant, a detailed microeconomic analysis of every cost component (labor, capital, maintenance, fuel, and so forth) permitted the calculation of total annual operating costs at roughly \$7.35, \$6.68 with \$0.67 savings, and \$6.39 with \$0.96 savings per mile for local, current limited, and modified bus operations, respectively (6).

Although labor costs represent 60 percent of peak operating expenses, more than 64 percent of total annual savings would result from lower peak vehicle requirements. Reducing the number of buses needed to maintain present schedules would cause the greatest proportion of cost savings obtainable through limited bus scheduling. Travel times computed previously for limited operations were divided by existing average peak headways to calculate declines in peak vehicles by route as shown in Figure 4. Decreases in fleet size ranged from 2 to 11 buses per route depending on stop service, route length, and headways (7).

Comparing adjusted limited and modified peak travel times to annual operating costs (computed by multiplying cost per bus-mile by total bus-miles) resulted in a set of bivariate equations applicable for predicting cost savings directly from decreases in peak travel times. With a correlation of r = 0.89, regression lines plotted in Figure 5 represent a linear relationship with plots that shift to the left for each degree of travel time reduction caused by limited or modified service scheduling. Checks made to compare the validity of predicted cost values with those obtained through microeconomic analysis were found to have a 95 percent fit between both cost derivations.

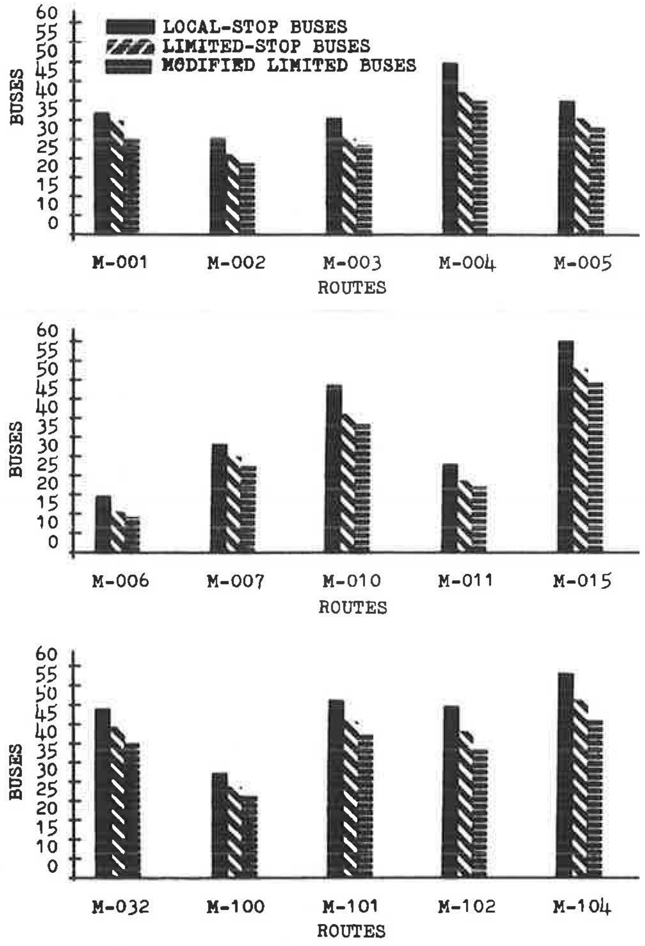


FIGURE 4 Peak vehicles by route and service type.

Table 1 applies regression equations derived from Figure 5 to estimate the total annual operating costs and savings predicted by route and stop service. Savings per route computed in Table 1 revealed modest declines of 9 to 10 percent in oper-

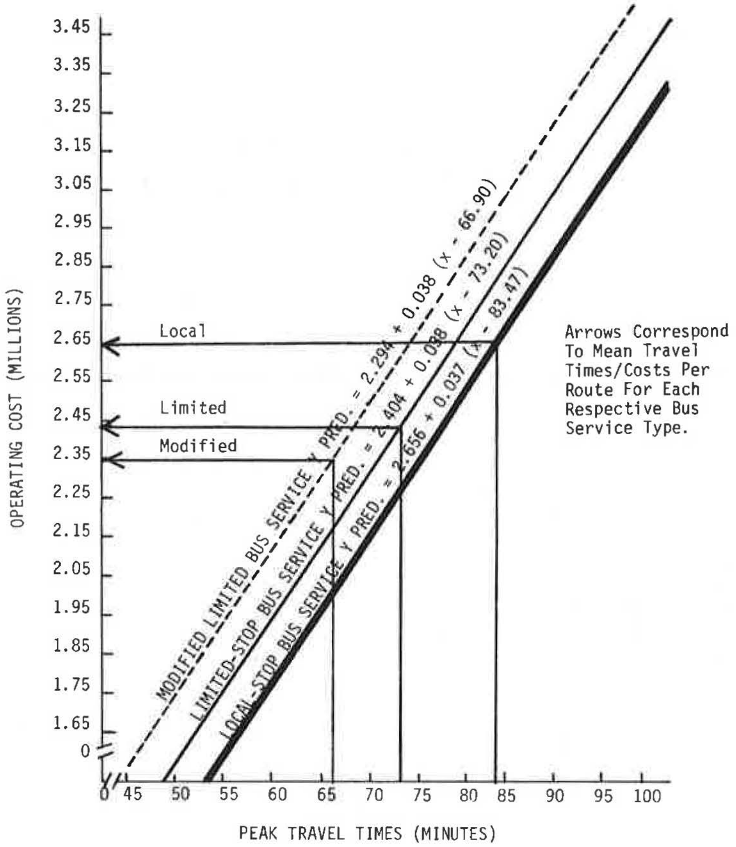


FIGURE 5 Relationship between peak operating cost and travel times.

ating costs for current limited service and marginally greater economies of from 13 to 14 percent for modified limited operations.

Present annual savings of more than $1.7 million are estimated for existing current limiteds on five routes and recently implemented modified limiteds on Route M-15. If modified limited service ran on all 15 routes with the minimum length necessary for noticeable user travel time savings, nearly $5.5 million would be saved annually. Although these savings are quite modest for major metropolitan bus systems, potential revenues from the retention of or

TABLE 1 Summary of Annual Total Costs per Route per Peak 6 Hours

ROUTE NUMBER	ROUTE NAME	LOCAL COSTS (MIL.)	LIMITED COSTS (MIL.)	MODIFIED COSTS (MIL.)	LIMITED SAVINGS (MIL.)	MODIFIED SAVINGS (MIL.)	PRESENT SAVINGS (MIL.)
M-001	5th+MAD. AV.	3.10	2.80	2.66	0.30	0.44	0.30
M-002	5th+MAD. AV.	2.80	2.53	2.42	0.27	0.38	----
M-003	5th+MAD. AV.	3.07	2.80	2.66	0.27	0.41	----
M-004	5th+MAD. AV.	2.76	2.48	2.39	0.28	0.37	0.28
M-005	5th+MAD. AV.	3.22	2.91	2.77	0.31	0.45	0.31
M-006	7th/AV. OF AM.	1.76	1.59	1.53	0.17	0.23	----
M-007	7th/AV. OF AM.	2.32	2.09	2.00	0.23	0.32	----
M-010	7th+8th AV.	2.69	2.45	2.30	0.24	0.39	0.24
M-011	9th+10th AV.	2.32	2.09	2.00	0.23	0.32	----
M-015	1st+2nd AV.	2.91	2.64	2.50	0.27	0.41	0.41 [a]
M-032	5th+MAD. AV.	2.32	2.09	2.00	0.23	0.32	0.23
M-100	AMSTERDAM AV.	2.54	2.29	2.19	0.25	0.35	----
M-101	3rd+LEX. AV.	3.44	3.10	2.96	0.34	0.48	----
M-102	3rd+LEX. AV.	3.14	2.83	2.69	0.31	0.45	----
M-104	BROADWAY	1.67	1.52	1.50	0.15	0.17	----
SYSTEMWIDE TOTALS =		40.06	36.21	34.57	3.85	5.49	1.77

[a] Since January 1982, modified limited buses have been operating on route M-15.

increase in discretionary (noncaptive) ridership may produce greater economies in the future.

Passenger Use and Preferences

The level of use and ridership preference for existing limited bus service were established by recording load profiles, interviewing CBD-bound riders, and counting passenger boardings during the simultaneous (bunched) arrival of both service types (8).

The load profile shown in Figure 6 is typical of routes using peak limited service and indicates similar ridership attraction for local and limited buses, a peaking of on-board occupancies just below the fringe of the CBD, and a tendency for limited buses to experience heavier boarding volumes near the outer terminals of CBD-oriented bus routes. Although no definitive findings can be inferred from the small percentage of trips surveyed, the use profiles obtained represent an affirmative indication that limited service (where provided) is being used to a significant degree.

A bus-stop questionnaire registered ridership preferences at high-volume locations for three routes with limited service. Questionnaire findings revealed that 50 to 60 percent of peak riders prefer using limiteds where they are available. This preference rate is supported by actual boarding counts taken to verify interview response rates. Only 12 percent of the responding limited bus riders walked beyond their nearest bus stop. Thus, a longer distance and a locally based demand market does exist in subregions between the range of local and express buses.

Observations made during the simultaneous arrival of local and limited buses indicated that from 42 to 74 percent of total boardings were made on buses providing limited operation. These findings support the results just described from on-board load profile and ridership questionnaire surveys.

Although modified limited service was not surveyed, secondary sources and data examining express-type operations point to significantly higher levels of passenger use (9,10).

RECOMMENDATIONS AND CONCLUSIONS

To evaluate routes for limited-service applications, five warrants to be considered before proposing practical limited-stop scheduling were developed from the findings reviewed in this paper:

1. Determine if a minimum user travel time savings of 6 min per trip or 12 min per day for limited

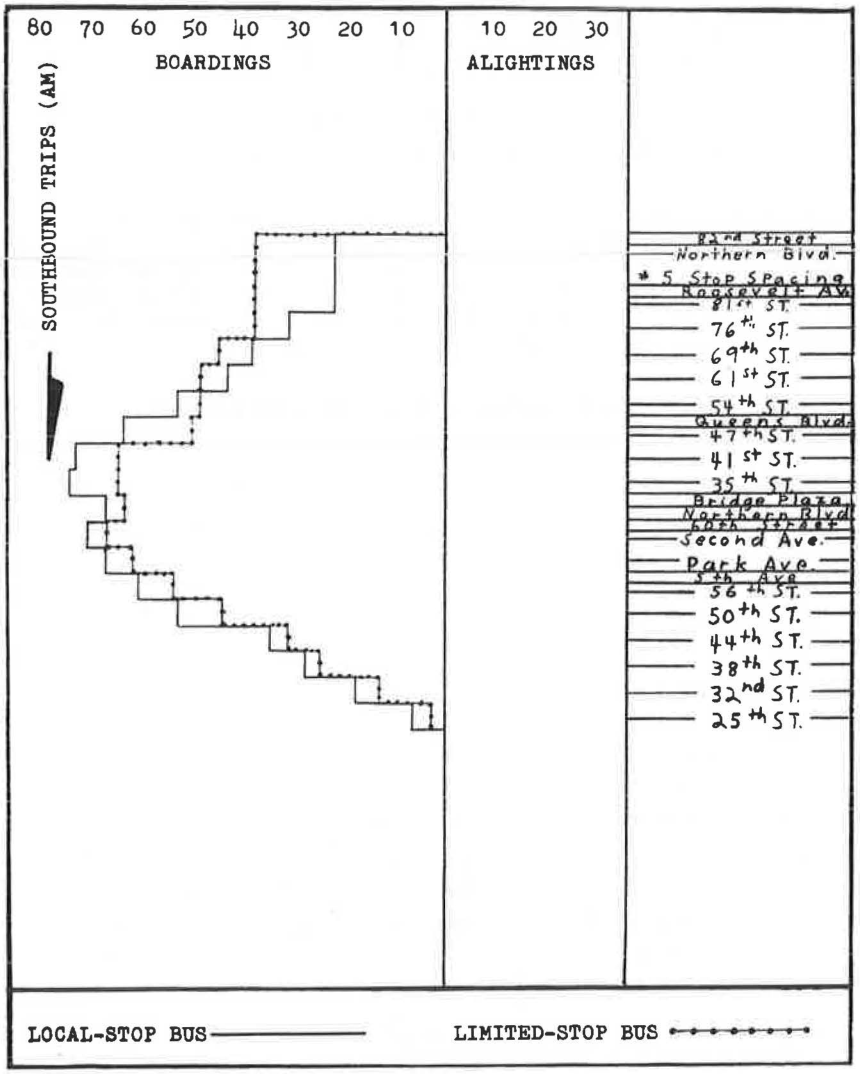


FIGURE 6 Passenger load profile for Route M-32.

bus passengers is feasible. User travel time reductions of more than 5 min per trip are usually necessary before time savings become perceivable to the riding public or significant enough to justify maintaining separate limited operations.

2. Analyze the ability to raise average operating speeds a minimum of 1 to 2 mph for limited bus trips if existing or revised route configurations, and stop frequency/walking distance to stop tradeoffs permit. In lower density cities, and where transportation system management (TSM) enhancements are included, increases in speeds from 3 mph over local buses are attainable.

3. Study the potential use of peak-period limited bus service by reviewing trip origin-destination and distribution counts per route section or zone. Relatively inexpensive surveys (as part of regular monitoring efforts) using questionnaires and boarding-alighting counts for routes meeting warrants 1 and 2 could be conducted to supplement existing data.

4. Estimate the impact of reducing peak vehicle requirements on routes where increases in on-board load factors (caused by a loss in seats per hour) could be alleviated by targeting peak-period users more efficiently between local and limited trips. The number of buses assigned as limiteds can be approximated by the percentage of longer distance trips expected per selected route.

5. Establish which stopping strategies for limited buses maximize ridership and access coverage. Stopping frequency configurations may include the following: (a) nodal or widely spaced distributions of bus stops at major activity points, (b) clustered or segmented patterns concentrating stops in residential and commercial catchment areas, and (c) combined nodal and clustered patterns that alternate stop frequencies by route segment to meet unique corridor trip distributions.

Schedules that permit riders to plan their arrivals, and the importance of comfort and convenience factors to express riders, may also apply to intraurban limited-stop bus users if significant quantitative and qualitative service improvements can be realized (10).

Difficulties in funding transit and the elimination of federal operating subsidies require an examination of differential fare policies for lowering operating deficits and earning surplus revenues from more affluent markets in order to maintain basic local service for all bus transit users.

Use of a package of low-cost TSM measures with limited operations could potentially double time and cost savings. Such measures can include reserved bus lanes, signal-timing optimization, route modifications, higher capacity vehicles, automatic monitoring techniques, and targeting marketing efforts.

The most essential differences between local and limited-stop bus operations have been summarized. Two sets of bivariate linear regression equations to facilitate the selection of routes for limited service by forecasting time and cost savings have been computed, and a list of five warrants derived from research findings to direct study or analysis projects has been provided.

Increases in operating speeds and travel time reductions resulting from the introduction of limited-stop bus service could produce substantial cuts in peak-period user travel times and total annual operating costs per bus-mile. Added savings from a faster type of modified limited service would largely result from its greater potential to attract additional ridership.

ACKNOWLEDGMENTS

Study findings used in this paper were taken from a three-part report compiled with the technical guidance of Polytechnic Institute of New York and the New York City Transit Authority. Research assistance provided by Roger Roess, Philip Grealy, and Nikos Theophilopoulos of Polytechnic Institute and Patrick Marmo, James Chin, and Alex Friedlander of the Transit Authority is sincerely appreciated. Comments from Clyde Jasinski, Frank Gerace, and Terry Murawski of the New York State Department of Transportation are gratefully acknowledged. Responsibility for calculation accuracy, conclusions, and analysis methods recommended in this paper is solely that of the author.

REFERENCES

1. Edwards & Kelcey, Inc. An Evaluation of Surface Transit System Performance. Technical Memo 2. NYCDOT and NYDCP, New York, Sept. 6, 1978.
2. A.R. Eriksen and E.A. Beimborn. Effectiveness of Alternative Downtown Area Bus Distribution Systems. In Highway Research Record 459, HRB, National Research Council, Washington, D.C., 1973, pp. 29-39.
3. V.R. Vuchic et al. Transit Operating Manual, 2nd ed. Pennsylvania Department of Transportation, Harrisburg, 1978.
4. Bus Schedules and Running Times for Routes Operating in Manhattan. Transit Surface Division, New York City Transit Authority and Manhattan and Bronx Surface Transit Operating Authority, 1981.
5. Institute of Transportation Engineers. Transportation and Traffic Engineering Handbook. Prentice Hall, Englewood Cliffs, N.J., 1976.
6. K. Gilbert. TSM: Handbook of Manual Analysis Techniques for Transit Strategies. UMTA TSM Prototype Study Program; Alan M. Voorhees & Associates, Inc., Dallas-Fort Worth, Tex., May 1981.
7. Summary of Weekday Schedule Statistics by Route--9/80 to 9/81. Surface Division, New York City Transit Authority. Brooklyn, N.Y., July 1981.
8. Manual of Traffic Engineering Studies, 4th ed. Institute of Transportation Engineers, Arlington, Va., 1976.
9. J.M. Zupan and B. Pushkarev. Where Express Buses Work. In Transportation Research Record 626, TRB, National Research Council, Washington, D.C., 1977, pp. 35-38.
10. W.P. McShane, P. Menaker, R.P. Roess, and J.C. Falcocchio. Transit Ridership in an Intense Transit Environment: Some Observations. In Transportation Research Record 746, TRB, National Research Council, Washington, D.C., 1980, pp. 1-7.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Operational Evaluation of Bus Priority Strategies

NAGUI M. ROUPHAIL

ABSTRACT

The primary objective of this study was to evaluate the impact of the use of two bus priority techniques on the operation of bus and nonbus traffic in a simulated environment. The strategies studied were (a) contra-flow bus lane on a downtown street and (b) signal settings based on minimizing passenger instead of vehicle delays. The operational setting reflected actual observations on a Chicago downtown street where a contra-flow bus lane was installed in the summer of 1980. It was found that predicted bus operation improved significantly as a result of dedicating an exclusive lane to bus traffic, as demonstrated by an increase in overall bus speed on the route. The signal priority technique implemented by means of the TRANSYT-7F model enhanced bus operation even further. The degree of bus operation improvement, however, was dependent on whether the buses operated in mixed traffic or on exclusive lanes. It was also noted that total vehicle-miles of travel for nonbus traffic decreased after the implementation of the bus lane. Some improvements in nonbus traffic operation on the study section may be attributed to that factor. Finally, a limited field study was conducted to test bus performance indices predicted by the TRANSYT model. The observed and simulated overall bus travel speeds were found to compare favorably at the 5 percent significance level.

In August 1980 Chicago created two contra-flow bus lanes on the downtown portion of Adams Street and Jackson Boulevard. These bus lanes (the first of four such installations in the Loop) were implemented as part of an overall plan aimed at reducing carbon monoxide emissions in Chicago's central business district. Other techniques included the implementation of a real-time traffic signal control system and a reduction of on-street parking opportunities (1).

The separation of bus traffic from automobile traffic was viewed as an effective means of decreasing automobile delays caused by buses stopping along the route, as well as of improving bus transit operation and reliability.

A review of accident frequency after the implementation of the bus lanes indicated that bus-vehicle accident rates dropped, while bus-pedestrian accident rates sharply increased. It appeared that pedestrians were still accustomed to the previous one-way operation on the street where the bus lanes were introduced. Strategies are presently being studied to tackle the problem of enforcement of priority treatment for buses (2). That work, however, was beyond the scope of this study, which considers only operational impacts of the bus lane implementation.

STUDY OBJECTIVES AND SCOPE

This study was aimed at evaluating two preferential bus treatments applied to a downtown Chicago street from a strictly operational standpoint, using the tool of digital simulation.

The basis for the evaluation procedure is that buses (as well as automobile traffic) operate in a signalized control environment and their performance is greatly affected by the signal settings adopted on the bus route. Levinson et al. (3), for example, stated that bus delays at traffic signals constitute 10 to 20 percent of overall bus trip time and are the cause of almost 50 percent of all delays.

The relationship between bus performance and priority techniques such as the use of an exclusive lane or signal settings is therefore the focus of this study. The following specific objectives were addressed:

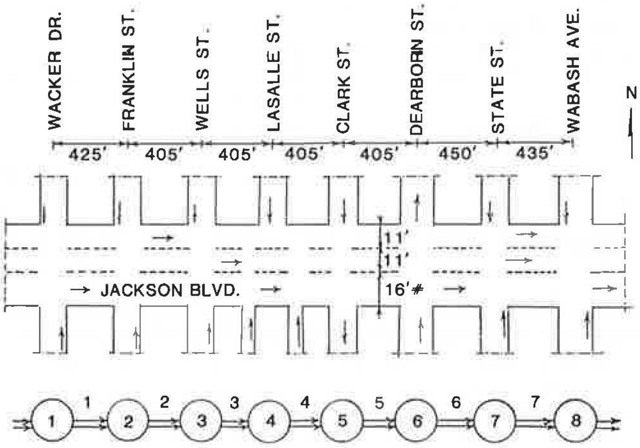
1. To identify signal-related and geometric-related bus priority techniques on Jackson Boulevard in the Chicago Loop and to develop a set of distinct priority strategies,
2. To evaluate each strategy developed in Objective 1 using existing traffic analysis techniques, and
3. To recommend a set of actions for enhancing bus operations on the study section.

Only operational indices such as delays, stops, and speeds were investigated. No attempt was made to study the short- and long-term safety impacts of the contra-flow bus lane project.

SITE DESCRIPTION

Schematic representations of the study site before and after the installation of the contra-flow bus lane are shown in Figures 1 and 2, respectively.

Originally, Jackson Boulevard was a one-way eastbound arterial from Jefferson Street (not shown) to Michigan Avenue (not shown). Total pavement width of



*INCLUDES 7' PARKING LANE

FIGURE 1 1975 network and link-node scheme.

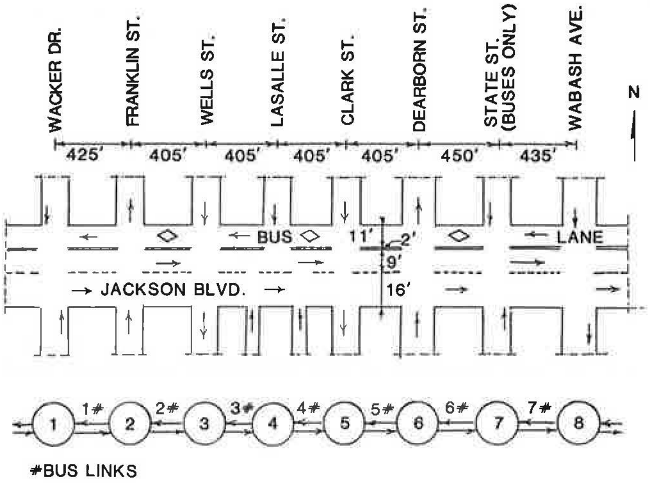


FIGURE 2 1981 network and link-node scheme.

38 ft was provided, including a 7-ft parking lane on the south side of the street and a three-lane travel section throughout. Twenty-four-hour counts taken between Dearborn and Clark streets gave an estimated 1975 average daily traffic (ADT) count of 13,277 vehicles, of which approximately 5 percent were buses operating in mixed traffic lanes.

After the creation of the bus lanes, the eastbound traffic was confined to two lanes, each 9 ft wide. Bus lanes were designed by 2-ft-long painted medians and had a width of 11 ft. Appropriate signing and signaling changes were also introduced. A 1980 count on Jackson Boulevard between Dearborn and Clark streets showed a 17 percent drop from the 1975 counts, down to 11,042 vehicles per day.

The subsequent evaluation schemes were simulated for representative weekday evening peak-hour (4:00 to 5:00 p.m.) traffic on Jackson Boulevard in 1975 (before bus lane) and 1981 (after bus lane).

BUS PRIORITY SCHEMES

To ascertain the potential effectiveness of the bus-lane operation and the impact on nonpriority traffic, six distinct signal and geometric control strategies were formulated for the study section:

1. Base condition (BC) describes traffic conditions and controls in existence before the bus lanes were installed (1975);
2. Optimized base condition (OBC) describes traffic conditions and controls similar to those of BC, except that signal settings are adjusted for minimum vehicular delays and stops;
3. Priority optimized base condition (POBC) describes traffic conditions and controls similar to those of BC, except that signal settings are adjusted for minimum passenger delays and stops;
4. Bus-lane operation (BL) describes traffic conditions and controls in existence approximately 1 year after the contra-flow bus lane was installed (1981);
5. Optimized bus-lane operation (OBL) describes traffic conditions and controls similar to those of BL, except that signal settings are adjusted for minimum vehicular delays and stops; and
6. Priority optimized bus-lane operation (POBL) describes traffic conditions and controls similar to those of BL, except that signal settings are adjusted for minimum passenger delays and stops.

The cycle length was fixed at 65 sec under all strategies and, except for one or two cases, all signalized intersections operated in two-phase mode.

Thus the prescribed treatments cover a wide range of bus operation improvement techniques, ranging from a do-nothing alternative as in BC to a combined signal and right-of-way priority for bus traffic in POBL. Not included in this analysis are bus signal preemption techniques that require special bus detection equipment or on-board devices for signal green time extension or red time truncation (4).

The analysis tool for this study was a recently developed version of the TRANSYT model, TRANSYT-7F, described hereafter (5).

TRANSYT-7F

Traffic Network Study Tool (TRANSYT) is a tool for optimizing traffic-signal systems on urban street networks. The 7F version has been developed recently in part to accommodate U.S. conventions and terminology. A recent application of TRANSYT-7F has been to assess the impact of traffic signal coordination on fuel conservation as part of an 11-city, National Signal Timing Optimization Project (6).

Among the most attractive features in TRANSYT, which had direct application to this study, is the concept of multiple links sharing one stop line. Thus a lane carrying mixed traffic (BC, OBC, and POBC) was entered in TRANSYT as two distinct links, each carrying one type of vehicle. The concept was again used to devise signal priority techniques for bus traffic. This was done by specifying link weights that were proportional to the average vehicle occupancy on the link. Because the objective function in TRANSYT is a weighted (by link) function of vehicle delays and stops, the optimum signal settings automatically incorporated a degree of priority for the designated priority traffic.

It should be noted that TRANSYT does not guarantee a global optimum solution (7), in part because no optimization of cycle lengths or phasing sequence is carried out. Some of these shortcomings have been alleviated in later versions of the model (8).

DATA PREPARATION AND COLLECTION

The following sections summarize the TRANSYT data needed to carry out the prescribed evaluation schemes.

Network Geometry

Lane configurations, intersections, geometrics, and bus links were gathered from street maps provided by the city of Chicago. The study section was bounded by Wacker Drive on the west and Wabash Avenue on the east. Information was coded directly into TRANSYT-7F via a link-node scheme shown in Figures 1 and 2.

Signal Settings

Copies of the traffic signal timing schedule furnished by the city of Chicago were used to code signal timing intervals directly into TRANSYT. Some adjustments were made in the "after" conditions (i.e., BL, OBL, and POBL) to account for bus traffic in two-way operation and for the conversion of some north-south cross streets from two-way to one-way traffic.

Saturation Flow Rates

Because of the high density of pedestrian traffic in the study section, the TRANSYT-7F default saturation flows of 1,700 vehicles per hour of green (vphg) and 1,600 vphg for through and turning traffic, respectively, could not be applied. Instead vehicle start-up delays and discharge headways were measured directly in the field for various lane types. A summary of the results is given in Table 1.

TABLE 1 Saturation Flow Study Results

Lane Channelization	Mean Start-Up Delay (sec)	Mean Departure Headway (sec)	Measured Saturation Flow Rate (vphg)	TRANSYT Default (vphg)
Through traffic only	3.49	2.98	1,200	1,700
Through and right[a] turns, right-turn lanes	4.02	3.53	1,020	1,600-1,700
Through and left[a] turns, left-turn lanes	3.82	3.59	1,000	1,600-1,700
Exclusive bus lanes	—[b]	—[b]	—[c]	600-800

[a] Lane types combined due to the small differences observed in the field.
[b] Inadequate sample size.
[c] Inadequate sample size; default value 600 buses per lane per hour of green was used.

Bus Flow Data

Information about bus routes, schedules, and stops on Jackson Boulevard was provided by the Chicago Transit Authority. The data were subsequently coded into TRANSYT-7F.

Traffic Volume Data

A complete set of directional and turning movement counts was not available for the "before" study period. This constituted a serious obstacle to the evaluation process because there was no possibility of collecting volume data that had not already been obtained. A logical procedure was devised to produce realistic estimates of missing counts on the basis of available turning movement, directional, and cordon counts in the study area (9). The final volume estimates were subsequently reviewed by traffic personnel in Chicago and coded into TRANSYT-7F. It is interesting to note that previous work by Kreer (10) indicated that TRANSYT measures of effectiveness are not very sensitive to errors in traffic volume estimations. It was shown that the introduction of a random deviate with mean 1 and standard deviation 0.2 on each link volume resulted in variations of less than 5 percent in the performance index in TRANSYT.

No such difficulties were encountered in the "after" condition because there were adequate volume counts in that particular period and missing counts were obtained directly from field measurements.

RESULTS

System Configuration Changes

A number of changes occurred on the street system during the 6 years separating the base and bus lane conditions described earlier. These included modifications in network geometry, traffic signal setting, and traffic volumes. Geometric changes can be observed in Figures 1 and 2. It was estimated that by removing one lane of traffic from the eastbound approach, the capacity of the eastbound movement would be reduced by 1,100 vphg (see Table 1). The westbound movement capacity on the other hand is increased by 600 buses per hour (TRANSYT-7F default value). Thus a net capacity loss of 500 vphg occurred in the "after" condition. In addition, both cordon counts and short-term field counts indicated a reduction in automobile traffic using the facility (11,12). Hence, the resulting situation (drop in volume and capacity) offered a unique opportunity for conducting an unbiased evaluation of the traffic signal and geometric priority schemes based on comparable volume-to-capacity ratios in the before and after conditions.

Average Speed

TRANSYT calculates average speed as the ratio of total travel (in vehicle-miles per hour) to total travel time (in vehicle-hours per hour). Only internal links (i.e., arterial links) are included in calculating speed on the network. When links are designated for bus travel, bus dwell times (assumed to be constant at 20 sec per stop) are incorporated as part of the travel time.

Table 2 gives a summary of the results for average vehicle speed. As anticipated, the simulated network-wide speed increased significantly when optimum TRANSYT signal settings were implemented (OBC, POBC, OBL, and POBL). Automobile traffic speed slightly decreased under the OBL and POBL strategies, compared with OBC and POBC, with turning traffic exhibiting the greatest reduction. This is one result of switching from one-way to two-way operation on the arterial and the associated traffic delays (to left turns) caused by opposing bus traffic and pedestrian interference. The most notable impact given in Table 1, however, is a dramatic increase in the simulated overall bus speeds under exclusive bus lane operation, which ranged from 0.88 to 1.152 mph in mixed traffic and from 4.86 to 6.4 mph with the exclusive lane. The fact that the simulated bus speed decreased under OBL, compared with BL, indicates that additional green time was allocated to the cross-street traffic to minimize over-

TABLE 2 Predicted Travel Speeds (mph) for Jackson Boulevard Traffic

Strategy	Network-Wide[a]	All Traffic	Through Traffic	Right Turns	Left Turns	Bus Traffic[b]
Base condition	3.63	4.720	4.320	5.944	11.063	0.879
Optimized base condition	6.27	11.395	11.133	13.519	13.287	1.146
Priority optimized base condition	6.19	11.889	11.436	13.805	13.949	1.152
Bus-lane operation	3.82	10.142	11.642	8.301	10.426	5.236
Optimized bus-lane operation	6.02	10.117	12.124	7.277	10.104	4.862
Priority optimized bus-lane operation	5.92	10.251	12.668	8.035	9.366	6.397

[a] Represents average running speed (excluding bus dwell times).
[b] Represents average overall bus speed (including dwell time of 20 sec/stop).

TABLE 3 Predicted Delays in Vehicle-Hours per Hour (passenger-hours per hour) for Jackson Boulevard Traffic

Strategy	Network-Wide	All Traffic	Through Traffic	Right Turns	Left Turns	Bus Traffic	Cross-Street Traffic
Base condition	115.501 (304.178)	90.701 (267.474)	78.480 (249.387)	8.223 (12.170)	3.998 (5.917)	9.114 (145.824)	24.800 (36.704)
Optimized base condition	58.428 (122.688)	26.736 (65.784)	21.510 (58.050)	2.488 (3.682)	2.738 (4.052)	1.812 (28.992)	31.692 (46.904)
Priority optimized base condition	59.464 (118.840)	23.960 (59.294)	19.339 (52.455)	2.198 (3.253)	2.423 (3.586)	1.633 (26.606)	35.504 (52.546)
Bus-lane operation	(76.504) (138.373)	24.424 (61.295)	16.800 (24.864)	1.872 (2.770)	4.020 (5.949)	1.732 (27.712)	52.080 (77.087)
Optimized bus-lane operation	44.247 (96.384)	23.206 (65.243)	15.132 (22.395)	2.114 (3.129)	3.832 (5.671)	2.128 (34.0480)	21.041 (31.141)
Priority optimized bus-lane operation	45.204 (86.851)	20.578 (50.405)	13.502 (19.983)	1.805 (2.671)	3.897 (5.767)	1.374 (21.984)	24.626 (36.446)

all delays and stops on the network. Because the total available green time is fixed (cycle = 65 sec), an inevitable decrease in bus green times, and subsequently in simulated overall bus travel speed, occurred.

Finally, optimum bus performance was attained when passenger delays were considered in developing the signal-timing plans. The improvement in bus performance, however, was less than 1 percent under mixed traffic operation (POBC versus OBC) but more than 30 percent with the exclusive lane.

Vehicle and Passenger Delays

Delay in TRANSYT is defined as the stopped time on the link due to signal timing only, including bus traffic. Table 3 gives a summary of the results for simulated vehicle and passenger delays associated with each of the six strategies under study. Whereas vehicle delay is obtained directly from TRANSYT output, some calculations were necessary to estimate passenger delays. The latter were based on average vehicle occupancies on each link, as obtained from cordon counts taken at the Jackson Boulevard Bridge on the Chicago River. Values of 1.48 persons per car, 1.90 persons per taxi, and 16 persons per bus were derived. The average link occupancy was determined as

$$\text{Link } (j) \text{ occupancy} = \sum_{i=1}^{3} O_i P_{ij}$$

where O_i is vehicle occupancy for vehicle type i and P_{ij} is percentage of traffic volume on link j consisting of vehicle type i.

As indicated in Table 3, simulated vehicle delays decreased significantly as TRANSYT-7F optimum signal settings were implemented. The OBL operation resulted in the lowest network-wide vehicle delays, whereas the POBL operation resulted in the lowest overall passenger delays. It should be noted that the passenger-related performance measures are valid only for the set of vehicle occupancies stated previously. Another set of occupancies will probably result in different conclusions. Simulated delays on Jackson Boulevard did not vary considerably under the TRANSYT optimized signal settings, even under bus-lane operations (i.e., strategies OBC, POBC, OBL, and POBL), except for left-turn traffic delay, which increased as a result of the opposing bus traffic in the "after" condition.

Finally, simulated bus delays were generally lower under the exclusive bus lane, with optimum delays occurring with the POBL strategy.

FIELD VALIDATION OF RESULTS

A limited field study was conducted to validate the predicted bus performance measures obtained from the TRANSYT simulation runs. Overall bus travel speed was the targeted performance measure. In addition, bus operating parameters, such as occupancy and dwell times, were gathered to verify the original assumptions about their values in the TRANSYT runs.

Two observers on board the transit vehicle were used to gather the required data. One observer collected transit riding data, such as the number of passengers boarding and alighting at each station and dwell time at each bus stop. The second observer collected travel time, running time, and traffic-related delays on each link on the bus route. A total of five independent bus runs in the evening peak hour was conducted. This sample size gives estimates of mean travel speed within ±3 mph of the expected value (13). The results of these runs are summarized in Tables 4 and 5. Bus dwell times,

TABLE 4 Bus Operation on Jackson Boulevard—Field Measurements[a]

Link[b]	Bus Occupancy (passengers)	Dwell Time at Bus Stop (sec)[c]	Traffic Delays on Link (sec)	Overall Travel Time on Link (sec)
1	31.8	14	16	47
2	30.0	11	22	46
3	31.4	11	22	54
4	32.2	14	5	42
5	31.8	30	5	44
6	31.2	40	11	71
7	21.2	38	24	72
Total	29.9	15.8	105	376

[a] Includes average of five independent bus runs.
[b] See link designations in Figures 1 and 2.
[c] Includes passenger boarding/alighting times away from bus stops as well.

TABLE 5 Comparison of Overall Bus Travel Speeds (mph)

Bus Link[a]	Field Runs 1	2	3	4	5	Mean	TRANSYT Run[b]
1	7.02	6.15	7.44	6.73	2.89	6.06	5.71
2	4.84	5.02	10.50	5.02	4.93	6.06	5.82
3	6.88	6.38	6.16	6.50	6.50	6.48	6.53
4	5.92	6.47	6.95	8.59	9.59	7.50	5.59
5	8.37	6.42	6.14	5.31	5.21	6.29	5.05
6	4.57	2.35	5.01	4.50	5.37	4.36	4.02
7	5.00	2.75	5.18	3.20	5.09	4.24	4.21
Average	6.09	5.08	6.76	5.71	5.65	5.86	5.27

[a] Link designations are shown in Figure 2.
[b] Adjusted for variable dwell time on bus links.

ranging from 11 to 40 sec, were found to vary from one stop to another, with an average of 22.5 sec per stop. Although the average dwell time varied by only 2.5 sec per stop from the assumed value in TRANSYT (20 sec per stop), adjustments on individual link travel times in TRANSYT were made in order to reflect the observed changes in overall bus travel speeds on the individual links caused by dwell time variations. Mathematically, the adjusted link travel time is calculated as follows: Adjusted link travel time (vehicle-hours per hour) = TRANSYT-derived travel time + (Observed dwell time for bus stop on link in seconds - 20) x (Hourly bus volume)/3600. The adjusted link travel speed is then calculated as

Speed on link = Total travel on link (vehicle-miles per hour)/Adjusted link travel time (vehicle-hours per hour).

A comparison of observed and simulated link travel speeds is given in Table 5. A t-test for matched pairs was conducted on the difference between observed and simulated link travel speeds in each run (14). The results indicated that the two sets of speeds were not statistically different at the 5 percent significance level. That conclusion held true for all five pair-wise comparisons.

No formal validation effort was undertaken to verify automobile traffic performance in TRANSYT. However, floating car runs conducted by the city of Chicago in 1975 gave an estimated evening peak-hour traffic speed of 5.68 mph on the study section. This value compares favorably with the TRANSYT estimate of 4.72 mph given in Table 1.

SUMMARY AND CONCLUSIONS

Bus priority techniques on urban street networks have been adopted in many U.S. cities to increase the person-moving capacity of major travel corridors.

This study has focused on evaluating two techniques for bus priority, namely a reserved contra-flow bus lane on a downtown street and bus priority consideration in signal timing calculations at each intersection along the bus route.

The results of a simulation analysis applied to a downtown Chicago street indicated that the potential effectiveness of each strategy in improving bus performance depends on many factors, including the magnitude of nonbus traffic, capacity reductions for nonbus movements after implementing the reserved lane, bus dwell times, and, of course, the traffic signal settings along the bus route.

In general, simulated bus speeds increased when the signal settings incorporated some degree of priority for high-occupancy vehicles. That increase, however, was barely noticeable under mixed traffic operations (1.146 to 1.152 mph) but considerable under the reserved lane configuration (4.82 to 6.397 mph).

It was also noted that the TRANSYT optimized settings did not always result in improved bus performance because the objective function in TRANSYT considers all vehicle delays and stops on the network, not just those experienced on the bus route. The most consistent result, however, is a dramatic increase in predicted overall bus travel speeds under the reserved bus lane configuration, regardless of the signal control strategy adopted.

Finally, all of the prescribed impacts were concomitant with an observed reduction in nonbus traffic volume 1 year after the implementation of the contra-flow bus lane. Whether a route shift by motorists who originally traveled on Jackson Boulevard occurred as a result of the increased congestion for nonbus traffic after the bus lane was installed is yet to be thoroughly investigated. Nevertheless, it is imperative that both route and modal shifts be monitored regularly after the implementation of bus priority techniques so that a comprehensive impact assessment analysis beyond the bus path may be undertaken.

ACKNOWLEDGMENTS

This study was sponsored in part through a University of Illinois, Chicago, Research Board Grant. The author wishes to thank John LaPlante and Jerry Sachno, Traffic Engineers with the city of Chicago, for supplying the data needed to conduct this study. Sincere thanks to Debbie Van Huis, Sandra Wichelecki, and Jeffery Monroe for their assistance in data collection and computer run analysis.

REFERENCES

1. T.P. Kaeser. Preferential Bus Treatments in Chicago's Central Area. Compendium of Technical Papers, 52nd Annual Meeting of the Institute of Transportation Engineers, Chicago, Ill., Aug. 1982.
2. J.J. Roark. Enforcement of Priority Treatment for Buses on Urban Streets. NCTRP Synthesis of Transit Practice 2. TRB, National Research Council, Washington, D.C., May 1982.
3. H.S. Levinson, C.L. Adams, and W.F. Hoey. Bus Use of Highways: Planning and Design Guidelines. NCHRP Report 155. TRB, National Research Council, Washington, D.C., 1975.
4. A.J. Richardson and K.W. Ogden. Evaluation of Active Bus-Priority Signals. In Transportation Research Record 718, TRB, National Research Council, Washington, D.C., 1979, pp. 5-12.
5. TRANSYT-7F User Guide. FHWA, U.S. Department of Transportation, Dec. 1981.
6. National Signal Timing Optimization Project: Summary Evaluation Report. FHWA, U.S. Department of Transportation, May 1982.
7. S.L. Cohen. Concurrent Use of the Maxband and TRANSYT Signal Timing Programs for Arterial Signal Optimization. Presented at 62nd Annual Meeting of the Transportation Research Board, Washington, D.C., 1982.
8. TRANSYT-7F. Release 3. FHWA, U.S. Department of Transportation, May 1983.
9. J. Monroe. Analysis of a Volume Adjustment and Interpolation Method of Intersections. M.S. thesis. University of Illinois, Chicago, 1983.
10. J.B. Kreer. Factors Affecting the Relative Performance of Traffic Responsive and Time-of-Day Traffic Signal Control. Transportation Research, Vol. 10, 1976.
11. 1975 Cordon Count, Chicago Central Business District. Chicago, Ill., 1975.
12. 1981 Cordon Count, Chicago Central Business District. Chicago, Ill., 1981.
13. Manual of Traffic Engineering Studies, 4th ed. Institute of Transportation Engineers, Washington, D.C., 1976.
14. D.L. Harnett. Introduction to Statistical Methods, 2nd ed. Addison-Wesley, Reading, Mass., 1975.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Use of SUPERCALC to Compile and Report Statistics in Public Transportation

ROBERT CHAPLEAU and KARSTEN G. BAASS

ABSTRACT

The aim of this paper is to demonstrate the usefulness of commercially developed and widely available software for solving problems of data analysis and statistical evaluation in transportation planning and operations. As an example, SUPERCALC, developed by Sorcim Corporation, is applied to the study of public transportation usage. The problem-solving illustration is composed of three parts: The first part involves the design of a basic worksheet (template), the second demonstrates the definition of a bus line and the preparation of a field sheet, and the third describes the compilation of observed data and the preparation of final and intermediate reports. The sample application shows that fairly difficult problems, which formerly would have required a mainframe computer and specialized knowledge of computer programming, can now be handled by this user-friendly and easily understood software. The application described was implemented on an Osborne 1 (64K) computer, a typical modern microcomputer. The low cost of this and similar microcomputers makes them particularly appealing for small, medium, and even larger transportation agencies.

Microcomputers are penetrating more and more into our everyday lives. Because of their personal character and ready availability they have initiated a revolution in our calculation habits similar to the one brought about by electronic calculators. This development is only beginning and, as Simkowitz and Manheim (1) suggest, ways of perceiving and solving problems may change completely because of the capabilities of these machines.

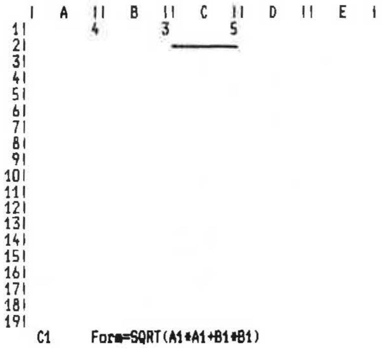
Development has been so rapid that software availability lags, and many of the newly developed programs for microcomputers still follow the old mainframe computer approach to programming without using the unique capabilities of the microcomputer to their fullest extent.

One of the advantages of the microcomputer is the availability of powerful commercial software developed for general applications such as wordprocessing programs (such as WORDSTAR), data management systems (such as DBASE II), and finally programs for handling numbers and complex mathematical equations (such as VISICALC or SUPERCALC and so on). These will be called "CALCs" in the remainder of this paper.

This latter type of software opens up enormous possibilities to the engineer working on the planning and operation of transportation systems because it does not require any specialized knowledge of programming languages but works somewhat like an enhanced electronic calculator. It allows the analyst to design field sheets, to compile data, and to produce reports easily and in an extremely user-friendly way. The concepts behind VISICALC, SUPERCALC, and the other CALCs are much the same and SUPERCALC (2) is used in this illustration. Some introductory explanations are necessary in order to understand the basics of this program. Its usefulness in transportation will then be illustrated by an application.

THE CALC PROGRAM

The memory of the microcomputer is subdivided into a worksheet or spreadsheet similar to a matrix with 63 columns and 254 rows. Each of these cells can contain data, complicated formulas, or alphanumeric information, or it can be used for graphic output. The width of the columns can be varied if necessary. Figure 1 shows an example of a worksheet.



```
    |  A  ||  B  ||  C  ||  D  ||  E  |
  1|        4      3      5
  2|               ______
  3|
  4|
  5|
  6|
  7|
  8|
  9|
 10|
 11|
 12|
 13|
 14|
 15|
 16|
 17|
 18|
 19|
     C1      Form=SQRT(A1*A1+B1*B1)
```

FIGURE 1 Simple problem solved by SUPERCALC.

For example, to calculate the length of the hypotenuse of a triangle whose two other sides are known, the formula SQRT(A1*A1 + B1*B1) is entered into cell C1. The program then calculates the results for all possible values put into cells A1 and B1 and shows the result in cell C1. The formula is not displayed in cell C1 but is stored and can be displayed by putting the cursor under cell C1. The formula will then be displayed at the bottom of the worksheet as shown in Figure 1. The result of the calculation in cell C1 can then be used for other calculations in other cells.

The ability to handle alphanumeric data enables titles and row and column headings to be written on the worksheet so the results can be presented in an appealing way. The analyst designs a worksheet in the same way that work would be done manually on a sheet of paper and no programming knowledge is necessary. Yet the program ensures efficient and rapid work. In many circumstances, this approach is superior to and much faster than the classical programming approach, as will be illustrated later.

A number of interactive commands allow data entry, and the updating, editing, saving, and printing of data and formulas in an extremely simple and user-friendly way. Some of these commands [see Osborne user's guide (2) or equivalent] include

- Data Commands

/Edit:	Transfers cell contents to entry line for editing.
/Format:	Specifies format for a given portion of the worksheet.

- Worksheet adjustment commands

/Delete:	Erases data from a specified column or row.
/Insert:	Inserts an empty column or row.
/Move:	Relocates a column or a row of data.
/Copy:	Duplicates data from source row or column to destination.
/Replicate:	Replicates source until specified range is filled.
/Title:	Provides method for fixing titles.

- File manipulation

/Load:	Loads and displays part or all of a disk file.
/Save:	Stores data from worksheet to disk.
/Output:	Prints results to printer or disk.

- General commands

/Zap:	Clears the entire worksheet of data.
/Quit:	Exits from SUPERCALC.

The copy and replicate commands deserve special mention because they are particularly useful in multiplying data in the worksheet. The format command, which can be used to design a field sheet or final report, is also helpful.

APPLICATION OF CALC IN PUBLIC TRANSPORTATION

The principal aim of this paper is to illustrate an elegant and efficient way to solve some of the everyday problems encountered by the transit planner without using any heavy computer hardware.

The particular usefulness of the microcomputer lies in its interactive capability. The computer operator, programmer, and analyst are all one person in this environment, reuniting the functions of design, calculation, and analysis that are essential in all engineering applications and that have been separated since the introduction of the mainframe computer. The feedback among data, program, and results is instantaneous and thus facilitates the engineer's work in design and daily operations, freeing him from dependence on computer programs and computer specialists.

Consider, as an example, the problem of transit route performance analysis and, especially, ridership reporting. Many programs exist in this field as is documented in the Software Source book of Microcomputers in Transportation (3), but these are mainly programs written in BASIC or similar programming languages.

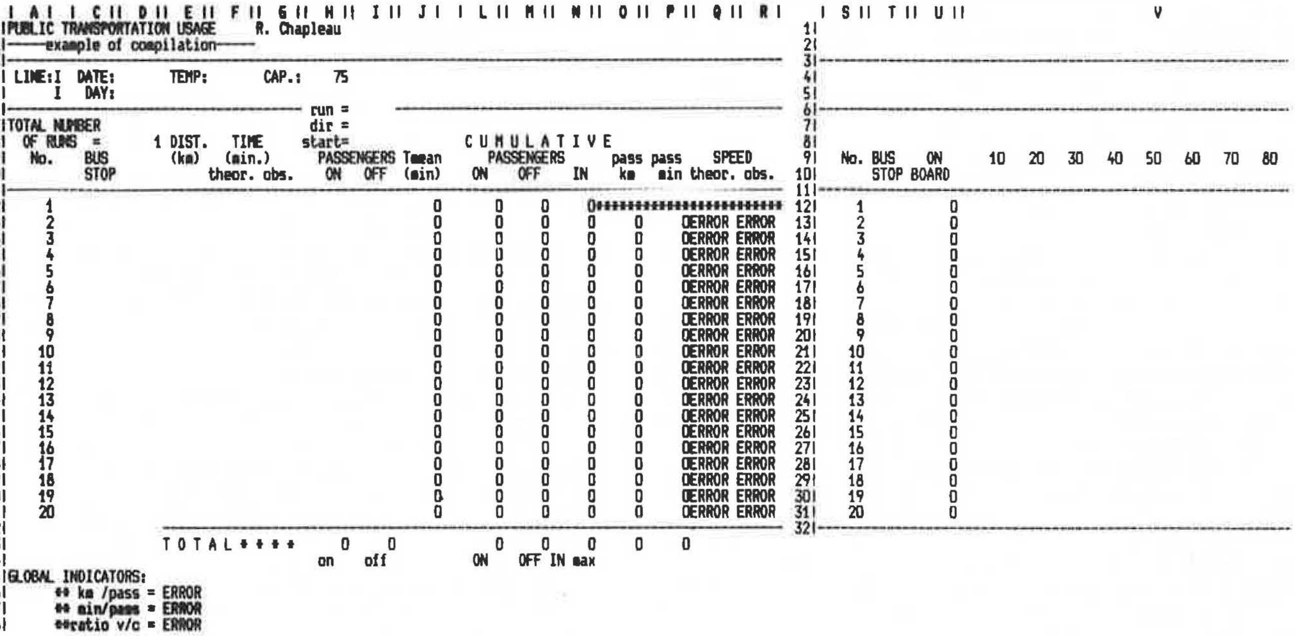
Procedures for the study of public transportation use (4) are well known. There are several activities related to these studies:

- Definition of bus lines with lists of stops and the distances between them;
- Data acquisition on board transit vehicles by an observer; and
- Compilation for a given time period of statistics such as time series distribution, maximum load point, and passenger-kilometers.

In a traditional computer environment at least three procedures would have to be programmed: (a) update of the file of bus routes (stops, speeds, and so forth); (b) data acquisition, verification, and validation; and (c) preparation of the report.

In the microcomputer environment a similar design can be used, which is much simplified by the use of CALC. The procedure has four levels:

1. General design of the spreadsheet data structure and analysis, together with the design of a field sheet for this particular problem.
2. Preparation of the field sheet for the particular transit line to be studied. This sheet can be used by the observer on the bus. The sample sheet



```
  | A |  | C || D || E || F || G || H || I || J |  | L || M || N || O || P || Q || R |     | S || T || U ||                V
 1|PUBLIC TRANSPORTATION USAGE      R. Chapleau                                               1|
 2|-----example of compilation-----                                                           2|
 3|-----------------------------------------------------------------------------------------  3|----------------------------------------------------
 4| LINE:I  DATE:        TEMP:        CAP.:    75                                              4|
 5|      I   DAY:                                                                              5|
 6|------------------------------------------- run =      -------------------------------------  6|----------------------------------------------------
 7|TOTAL NUMBER                                dir =                                           7|
 8|  OF RUNS  =      1 DIST.   TIME         start=          C U M U L A T I V E                 8|
 9|   No.     BUS      (km)   (min.)       PASSENGERS Tmean    PASSENGERS       pass pass   SPEED   9|  No. BUS    ON       10   20   30   40   50   60   70   80
10|           STOP             theor. obs.   ON   OFF (min)   ON     OFF      IN   km   min theor. obs. 10|      STOP BOARD
11|-----------------------------------------------------------------------------------------  11|----------------------------------------------------
12|     1                                              0      0      0      0#####################  12|    1          0
13|     2                                              0      0      0      0      0      0ERROR ERROR  13|    2          0
14|     3                                              0      0      0      0      0      0ERROR ERROR  14|    3          0
15|     4                                              0      0      0      0      0      0ERROR ERROR  15|    4          0
16|     5                                              0      0      0      0      0      0ERROR ERROR  16|    5          0
17|     6                                              0      0      0      0      0      0ERROR ERROR  17|    6          0
18|     7                                              0      0      0      0      0      0ERROR ERROR  18|    7          0
19|     8                                              0      0      0      0      0      0ERROR ERROR  19|    8          0
20|     9                                              0      0      0      0      0      0ERROR ERROR  20|    9          0
21|    10                                              0      0      0      0      0      0ERROR ERROR  21|   10          0
22|    11                                              0      0      0      0      0      0ERROR ERROR  22|   11          0
23|    12                                              0      0      0      0      0      0ERROR ERROR  23|   12          0
24|    13                                              0      0      0      0      0      0ERROR ERROR  24|   13          0
25|    14                                              0      0      0      0      0      0ERROR ERROR  25|   14          0
26|    15                                              0      0      0      0      0      0ERROR ERROR  26|   15          0
27|    16                                              0      0      0      0      0      0ERROR ERROR  27|   16          0
28|    17                                              0      0      0      0      0      0ERROR ERROR  28|   17          0
29|    18                                              0      0      0      0      0      0ERROR ERROR  29|   18          0
30|    19                                              0      0      0      0      0      0ERROR ERROR  30|   19          0
31|    20                                              0      0      0      0      0      0ERROR ERROR  31|   20          0
32|                  ----------------------------------------------------------------------  32|----------------------------------------------------
33|                  T O T A L * * * *    0    0             0      0      0      0      0
34|                                      on   off           ON     OFF IN max
35|GLOBAL INDICATORS:
36|       ** km /pass = ERROR
37|       ** min/pass = ERROR
38|       **ratio v/c = ERROR
```

FIGURE 2 Basic worksheet.

presented here follows closely the one used by the Montreal Urban Community Transit Commission.

3. Data entry on the field sheet and input of data to the microcomputer.
4. Preparation of intermediate and final reports.

DESIGN OF THE BASIC WORKSHEET

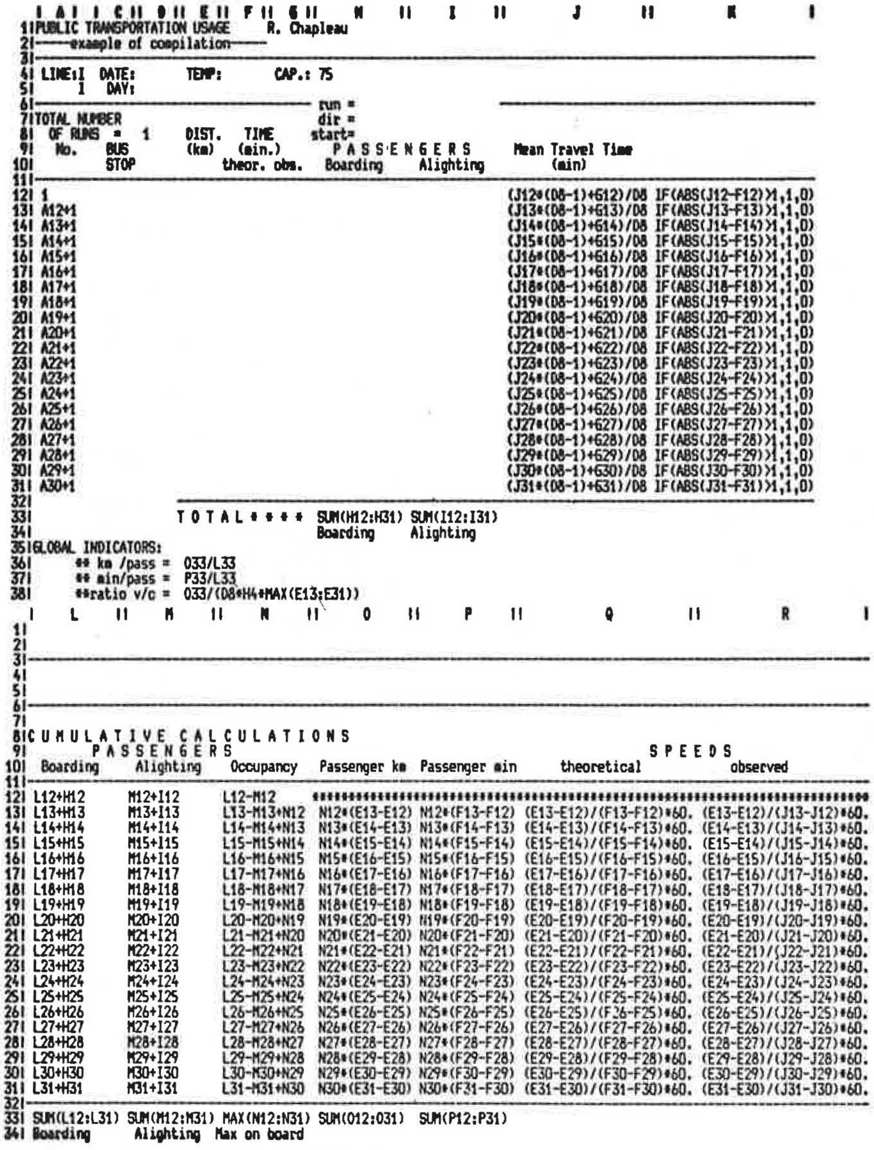
The practical illustration is based on an example with 20 bus stops, but CALC allows the number of stops to be modified easily (up to 254 if the memory of the microcomputer is large enough) by inserting new stops or deleting existing ones.

At the beginning of the design procedure, the kind of report to be produced in terms of format and graphic or written output must be defined. In the example the following information was required:

- All information contained on the basic field sheet such as line number, weather conditions, capacity of the bus, and time of departure of the run;
- Number of each bus stop, its name and location;
- Cumulative distance of each bus stop from the starting point;
- Cumulative time of arrival at each bus stop; and
- Number of boarding and alighting passengers.

The final report should contain cumulative calculations for a chosen period of the day: for example, volumes of boarding and alighting passengers, the maximum point load, and a graphic display of the passenger load profile for one or more bus runs. The report should also identify by an asterisk those links, between two stops, on which the theoretical average overall travel time differs by more than 1 min from the observed time. Several global indicators of performance such as overall travel speed, passenger-kilometers, and volume-to-capacity ratio should also be given on the report sheet.

When this basic worksheet has been designed, it can be saved on a disk file and used for any bus line to be studied. The basic worksheet is shown in Figure 2. Rows 1 to 11 essentially contain titles and headings for the report and the field sheet. The actual calculations are done in columns J to V over rows 12 to 31 using data that are contained in columns C to I over rows 12 to 31. The formulas introduced into the worksheet are shown in Figure 3. They are not displayed on the worksheet and are repro-



```
  | A |  | C || D || E || F || G ||   H    ||    I    ||        J        ||        K        |
 1|PUBLIC TRANSPORTATION USAGE     R. Chapleau
 2|-----example of compilation------
 3|-----------------------------------------------------------------------------------------
 4| LINE:I  DATE:        TEMP:       CAP.: 75
 5|      1   DAY:
 6|--------------------------------------- run =        ---------------------------------
 7|TOTAL NUMBER                             dir =
 8|  OF RUNS  =   1      DIST.   TIME     start=
 9|   No.     BUS       (km)   (min.)      P A S S E N G E R S     Mean Travel Time
10|           STOP              theor. obs.  Boarding     Alighting         (min)
11|-----------------------------------------------------------------------------------------
12| 1                                                            (J12*(D8-1)+G12)/D8 IF(ABS(J12-F12)>1,1,0)
13| A12+1                                                        (J13*(D8-1)+G13)/D8 IF(ABS(J13-F13)>1,1,0)
14| A13+1                                                        (J14*(D8-1)+G14)/D8 IF(ABS(J14-F14)>1,1,0)
15| A14+1                                                        (J15*(D8-1)+G15)/D8 IF(ABS(J15-F15)>1,1,0)
16| A15+1                                                        (J16*(D8-1)+G16)/D8 IF(ABS(J16-F16)>1,1,0)
17| A16+1                                                        (J17*(D8-1)+G17)/D8 IF(ABS(J17-F17)>1,1,0)
18| A17+1                                                        (J18*(D8-1)+G18)/D8 IF(ABS(J18-F18)>1,1,0)
19| A18+1                                                        (J19*(D8-1)+G19)/D8 IF(ABS(J19-F19)>1,1,0)
20| A19+1                                                        (J20*(D8-1)+G20)/D8 IF(ABS(J20-F20)>1,1,0)
21| A20+1                                                        (J21*(D8-1)+G21)/D8 IF(ABS(J21-F21)>1,1,0)
22| A21+1                                                        (J22*(D8-1)+G22)/D8 IF(ABS(J22-F22)>1,1,0)
23| A22+1                                                        (J23*(D8-1)+G23)/D8 IF(ABS(J23-F23)>1,1,0)
24| A23+1                                                        (J24*(D8-1)+G24)/D8 IF(ABS(J24-F24)>1,1,0)
25| A24+1                                                        (J25*(D8-1)+G25)/D8 IF(ABS(J25-F25)>1,1,0)
26| A25+1                                                        (J26*(D8-1)+G26)/D8 IF(ABS(J26-F26)>1,1,0)
27| A26+1                                                        (J27*(D8-1)+G27)/D8 IF(ABS(J27-F27)>1,1,0)
28| A27+1                                                        (J28*(D8-1)+G28)/D8 IF(ABS(J28-F28)>1,1,0)
29| A28+1                                                        (J29*(D8-1)+G29)/D8 IF(ABS(J29-F29)>1,1,0)
30| A29+1                                                        (J30*(D8-1)+G30)/D8 IF(ABS(J30-F30)>1,1,0)
31| A30+1                                                        (J31*(D8-1)+G31)/D8 IF(ABS(J31-F31)>1,1,0)
32|                  ----------------------------------------------------------------------
33|                  T O T A L * * * *  SUM(H12:H31) SUM(I12:I31)
34|                                     Boarding     Alighting
35|GLOBAL INDICATORS:
36|      ** km /pass =  O33/L33
37|      ** min/pass =  P33/L33
38|      **ratio v/c =  O33/(D8*H4*MAX(E13:E31))
  |   L    ||    M    ||    N    ||    O    ||    P    ||        Q        ||        R        |
 1|
 2|
 3|-----------------------------------------------------------------------------------------
 4|
 5|
 6|-----------------------------------------------------------------------------------------
 7|
 8|C U M U L A T I V E  C A L C U L A T I O N S
 9|      P A S S E N G E R S                                               S P E E D S
10| Boarding    Alighting   Occupancy  Passenger km  Passenger min     theoretical              observed
11|-----------------------------------------------------------------------------------------
12| L12+H12     M12+I12     L12-M12    **************************************************************
13| L13+H13     M13+I13     L13-M13+N12 N12*(E13-E12) N12*(F13-F12) (E13-E12)/(F13-F12)*60. (E13-E12)/(J13-J12)*60.
14| L14+H14     M14+I14     L14-M14+N13 N13*(E14-E13) N13*(F14-F13) (E14-E13)/(F14-F13)*60. (E14-E13)/(J14-J13)*60.
15| L15+H15     M15+I15     L15-M15+N14 N14*(E15-E14) N14*(F15-F14) (E15-E14)/(F15-F14)*60. (E15-E14)/(J15-J14)*60.
16| L16+H16     M16+I16     L16-M16+N15 N15*(E16-E15) N15*(F16-F15) (E16-E15)/(F16-F15)*60. (E16-E15)/(J16-J15)*60.
17| L17+H17     M17+I17     L17-M17+N16 N16*(E17-E16) N16*(F17-F16) (E17-E16)/(F17-F16)*60. (E17-E16)/(J17-J16)*60.
18| L18+H18     M18+I18     L18-M18+N17 N17*(E18-E17) N17*(F18-F17) (E18-E17)/(F18-F17)*60. (E18-E17)/(J18-J17)*60.
19| L19+H19     M19+I19     L19-M19+N18 N18*(E19-E18) N18*(F19-F18) (E19-E18)/(F19-F18)*60. (E19-E18)/(J19-J18)*60.
20| L20+H20     M20+I20     L20-M20+N19 N19*(E20-E19) N19*(F20-F19) (E20-E19)/(F20-F19)*60. (E20-E19)/(J20-J19)*60.
21| L21+H21     M21+I21     L21-M21+N20 N20*(E21-E20) N20*(F21-F20) (E21-E20)/(F21-F20)*60. (E21-E20)/(J21-J20)*60.
22| L22+H22     M22+I22     L22-M22+N21 N21*(E22-E21) N21*(F22-F21) (E22-E21)/(F22-F21)*60. (E22-E21)/(J22-J21)*60.
23| L23+H23     M23+I23     L23-M23+N22 N22*(E23-E22) N22*(F23-F22) (E23-E22)/(F23-F22)*60. (E23-E22)/(J23-J22)*60.
24| L24+H24     M24+I24     L24-M24+N23 N23*(E24-E23) N23*(F24-F23) (E24-E23)/(F24-F23)*60. (E24-E23)/(J24-J23)*60.
25| L25+H25     M25+I25     L25-M25+N24 N24*(E25-E24) N24*(F25-F24) (E25-E24)/(F25-F24)*60. (E25-E24)/(J25-J24)*60.
26| L26+H26     M26+I26     L26-M26+N25 N25*(E26-E25) N25*(F26-F25) (E26-E25)/(F26-F25)*60. (E26-E25)/(J26-J25)*60.
27| L27+H27     M27+I27     L27-M27+N26 N26*(E27-E26) N26*(F27-F26) (E27-E26)/(F27-F26)*60. (E27-E26)/(J27-J26)*60.
28| L28+H28     M28+I28     L28-M28+N27 N27*(E28-E27) N27*(F28-F27) (E28-E27)/(F28-F27)*60. (E28-E27)/(J28-J27)*60.
29| L29+H29     M29+I29     L29-M29+N28 N28*(E29-E28) N28*(F29-F28) (E29-E28)/(F29-F28)*60. (E29-E28)/(J29-J28)*60.
30| L30+H30     M30+I30     L30-M30+N29 N29*(E30-E29) N29*(F30-F29) (E30-E29)/(F30-F29)*60. (E30-E29)/(J30-J29)*60.
31| L31+H31     M31+I31     L31-M31+N30 N30*(E31-E30) N30*(F31-F30) (E31-E30)/(F31-F30)*60. (E31-E30)/(J31-J30)*60.
32|-----------------------------------------------------------------------------------------
33| SUM(L12:L31) SUM(M12:M31) MAX(N12:N31) SUM(O12:O31)  SUM(P12:P31)
34| Boarding      Alighting   Max on board
```

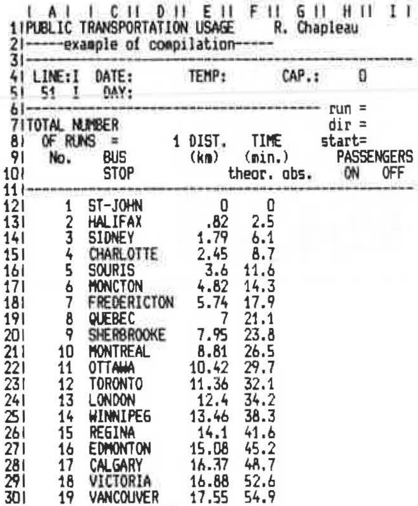
FIGURE 3 Formulas stored in basic worksheet.

duced here for explanatory purposes only. The ERROR messages in Figure 2 are normal because the program calculates, with the help of the formula of Figure 3, speeds and global indicators using times and distances, which are presently zero. CALC will produce meaningful values only when numbers are introduced into areas C1 to I20.

To understand the formulas, consider the number of passengers on the bus in column N of Figure 3 at the third bus stop. The number of boarding passengers corresponds to the current contents of cell L14 plus the contents of cell H14, which contains the number of passengers boarding and counted by the observer. Occupancy is calculated in column N as the difference between the number of boarding and alighting passengers plus those who are already in the bus from the preceding stop. The references to the cells can be interpreted as the indices of a matrix. One of the most useful characteristics of CALC is that all indices are automatically changed if a row (i.e., a bus stop) is deleted or inserted, so the worksheet can truly be used for any bus line with any number of stops.

FIELD SHEET

Using this basic design, a field sheet for a particular bus line can easily be prepared by saving from Figure 2 only columns A to I over rows 1 to 31 on a disk file. Adding the necessary information on bus stops such as location, distance, and travel times defines the field sheet shown in Figure 4. If separation lines are inserted, this sheet can be used directly on the bus (Figure 5).



```
  I A I  I C II  D II  E II  F II  G II  H II  I I
 1IPUBLIC TRANSPORTATION USAGE      R. Chapleau
 2I-----example of compilation-----
 3I-----------------------------------------------
 4I LINE:I  DATE:        TEMP:        CAP.:     0
 5I  51  I   DAY:
 6I-------------------------------------- run =
 7ITOTAL NUMBER                            dir =
 8I  OF RUNS  =         1 DIST.   TIME    start=
 9I   No.    BUS          (km)   (min.)    PASSENGERS
10I          STOP             theor. obs.   ON   OFF
11I-----------------------------------------------
12I      1  ST-JOHN          0      0
13I      2  HALIFAX        .82    2.5
14I      3  SIDNEY        1.79    6.1
15I      4  CHARLOTTE     2.45    8.7
16I      5  SOURIS         3.6   11.6
17I      6  MONCTON       4.82   14.3
18I      7  FREDERICTON   5.74   17.9
19I      8  QUEBEC           7   21.1
20I      9  SHERBROOKE    7.95   23.8
21I     10  MONTREAL      8.81   26.5
22I     11  OTTAWA       10.42   29.7
23I     12  TORONTO      11.36   32.1
24I     13  LONDON        12.4   34.2
25I     14  WINNIPEG     13.46   38.3
26I     15  REGINA        14.1   41.6
27I     16  EDMONTON     15.08   45.2
28I     17  CALGARY      16.37   48.7
29I     18  VICTORIA     16.88   52.6
30I     19  VANCOUVER    17.55   54.9
31I     20  YELLOWKNIFE     18     60
```

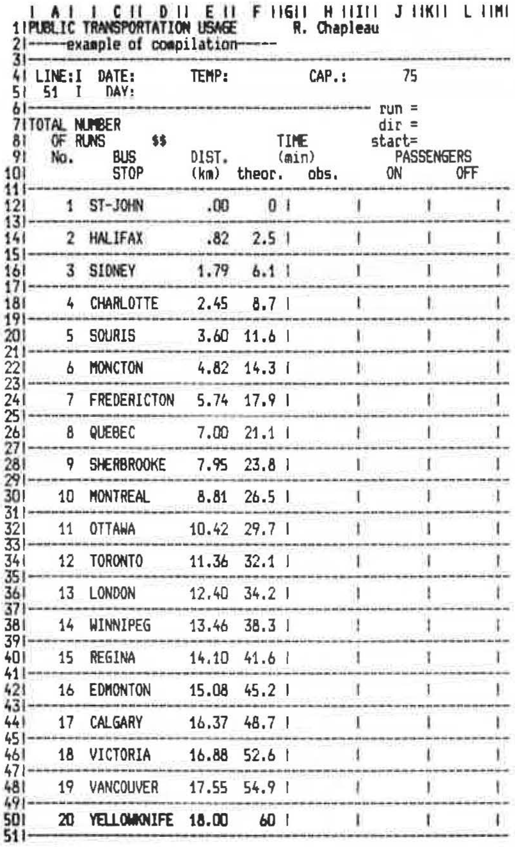
FIGURE 4 Field sheed stored on disk file.

OBSERVED DATA

The observed data are introduced directly from the field sheet into the microcomputer in an interactive way. In the example there are three runs, BA1, BA2, and BA3, on bus line 51 shown in Figure 6. The information is saved on disk file to be loaded later, if necessary, onto the basic worksheet of Figure 2.

REPORT

If a report is required for run BA1, for example, the basic worksheet (Figure 2) is first loaded from disk file into the memory of the computer and then the contents of disk file BA1 are inserted (using the command /Load) into this worksheet, which is equivalent to filling out the cells in columns C to I and rows 12 to 31. This automatically initiates the calculations described by the formulas shown in Figure 3, and this produces the report (Figure 7) for this run. If an average for the three runs is required, files BA2 and BA3 are successively loaded onto the basic worksheet and the final report (Figure 8) is obtained for the peak hour.



```
  I A I  I C II  D II  E II  F IIGII  H IIIII  J IIKII  L IIMI
 1IPUBLIC TRANSPORTATION USAGE      R. Chapleau
 2I-----example of compilation-----
 3I------------------------------------------------------------
 4I LINE:I  DATE:        TEMP:          CAP.:       75
 5I  51  I   DAY:
 6I---------------------------------------------- run =
 7ITOTAL NUMBER                                    dir =
 8I  OF RUNS       $$              TIME          start=
 9I   No.     BUS        DIST.     (min)           PASSENGERS
10I           STOP       (km)  theor.   obs.     ON        OFF
11I------------------------------------------------------------
12I      1  ST-JOHN       .00      0 I        I        I       I
13I------------------------------------------------------------
14I      2  HALIFAX       .82    2.5 I        I        I       I
15I------------------------------------------------------------
16I      3  SIDNEY       1.79    6.1 I        I        I       I
17I------------------------------------------------------------
18I      4  CHARLOTTE    2.45    8.7 I        I        I       I
19I------------------------------------------------------------
20I      5  SOURIS       3.60   11.6 I        I        I       I
21I------------------------------------------------------------
22I      6  MONCTON      4.82   14.3 I        I        I       I
23I------------------------------------------------------------
24I      7  FREDERICTON  5.74   17.9 I        I        I       I
25I------------------------------------------------------------
26I      8  QUEBEC       7.00   21.1 I        I        I       I
27I------------------------------------------------------------
28I      9  SHERBROOKE   7.95   23.8 I        I        I       I
29I------------------------------------------------------------
30I     10  MONTREAL     8.81   26.5 I        I        I       I
31I------------------------------------------------------------
32I     11  OTTAWA      10.42   29.7 I        I        I       I
33I------------------------------------------------------------
34I     12  TORONTO     11.36   32.1 I        I        I       I
35I------------------------------------------------------------
36I     13  LONDON      12.40   34.2 I        I        I       I
37I------------------------------------------------------------
38I     14  WINNIPEG    13.46   38.3 I        I        I       I
39I------------------------------------------------------------
40I     15  REGINA      14.10   41.6 I        I        I       I
41I------------------------------------------------------------
42I     16  EDMONTON    15.08   45.2 I        I        I       I
43I------------------------------------------------------------
44I     17  CALGARY     16.37   48.7 I        I        I       I
45I------------------------------------------------------------
46I     18  VICTORIA    16.88   52.6 I        I        I       I
47I------------------------------------------------------------
48I     19  VANCOUVER   17.55   54.9 I        I        I       I
49I------------------------------------------------------------
50I     20  YELLOWKNIFE 18.00     60 I        I        I       I
51I------------------------------------------------------------
```

FIGURE 5 Field sheet used on a bus.

CONCLUSIONS

The application of CALC to the case of transit surveys is efficient and fast. The worksheet can easily be adapted to fit all possible transit lines and titles; column headings and row headings can be modified as necessary for use by different transit authorities. The same basic CALC program can be adapted to other applications in the transit field; for example, to public transportation speed and delay studies. There are also many applications in the traffic engineering field such as spot speed studies and travel time and delay studies. These problems, which are extremely labor intensive and costly to solve, can now be tackled in a more global way by one person who designs the worksheet, inputs the data, and obtains the results, thus eliminating the time-consuming and costly intermediate steps of programming and analysis by a computer specialist.

The use of readily available and transferable mass-produced software such as CALC for the solution of day-to-day problems in transportation operations and planning is highly recommended, because it is

```
   | A |  | C || D || E || F || G || H ||  I |
 1|PUBLIC TRANSPORTATION USAGE     R. Chapleau
 2|-----example of compilation-----
 3|-----------------------------------------------
 4| LINE:I  DATE:150683 TEMP: clear CAP.:     75
 5|  51  I    DAY:monday
 6|------------------------------------ run = BA1
 7|TOTAL NUMBER                          dir =WEST
 8|  OF RUNS  =         1 DIST.  TIME   start=07h00
 9|   No.      BUS       (km)  (min.)     PASSENGERS
10|            STOP           theor. obs.   ON   OFF
11|-----------------------------------------------
12|       1  ST-JOHN        0     0     0   10     0
13|       2  HALIFAX      .82   2.5     3    5     2
14|       3  SIDNEY      1.79   6.1     6    5     2
15|       4  CHARLOTTE   2.45   8.7     9    3     3
16|       5  SOURIS       3.6  11.6    12    4     0
17|       6  MONCTON     4.82  14.3    15    2     6
18|       7  FREDERICTON 5.74  17.9    18    0     1
19|       8  QUEBEC         7  21.1    21    7     2
20|       9  SHERBROOKE  7.95  23.8    24   12     0
21|      10  MONTREAL    8.81  26.5    27    8     3
22|      11  OTTAWA     10.42  29.7    30    5     2
23|      12  TORONTO    11.36  32.1    33    4     0
24|      13  LONDON      12.4  34.2    36    1     1
25|      14  WINNIPEG   13.46  38.3    39    6     0
26|      15  REGINA      14.1  41.6    42    8     2
27|      16  EDMONTON   15.08  45.2    45    0     0
28|      17  CALGARY    16.37  48.7    48    0     4
29|      18  VICTORIA   16.88  52.6    51    7     0
30|      19  VANCOUVER  17.55  54.9    54    1    33
31|      20  YELLOWKNIFE   18    60    60    0    27
32|                                   ------------
33|                                         88    88
```

```
 | A |  | C || D || E || F || G || H ||  I |
PUBLIC TRANSPORTATION USAGE     R. Chapleau
-----example of compilation-----
-----------------------------------------------
 LINE:I  DATE:150683 TEMP: clear CAP.:     75
  51  I    DAY:monday
------------------------------------ run = BA2
TOTAL NUMBER                          dir =WEST
  OF RUNS  =         2 DIST.  TIME   start=07h15
   No.      BUS       (km)  (min.)     PASSENGERS
            STOP           theor. obs.   ON   OFF
-----------------------------------------------
       1  ST-JOHN        0     0     0    8     0
       2  HALIFAX      .82   2.5     2    3     1
       3  SIDNEY      1.79   6.1     5    5     3
       4  CHARLOTTE   2.45   8.7    10    4     2
       5  SOURIS       3.6  11.6    12    3     1
       6  MONCTON     4.82  14.3  15.5    0     4
       7  FREDERICTON 5.74  17.9  19.2    1     0
       8  QUEBEC         7  21.1  21.5    8     4
       9  SHERBROOKE  7.95  23.8  24.6   16     2
      10  MONTREAL    8.81  26.5    27    5     5
      11  OTTAWA     10.42  29.7  30.5    4     4
      12  TORONTO    11.36  32.1    33    3     0
      13  LONDON      12.4  34.2    35    2     3
      14  WINNIPEG   13.46  38.3  39.2    8     5
      15  REGINA      14.1  41.6    43    4     3
      16  EDMONTON   15.08  45.2    46    0     5
      17  CALGARY    16.37  48.7  49.5    0     8
      18  VICTORIA   16.88  52.6    54    2     5
      19  VANCOUVER  17.55  54.9    57    2    21
      20  YELLOWKNIFE   18    60    61    0     2
                                   ------------
                                         78    78
```

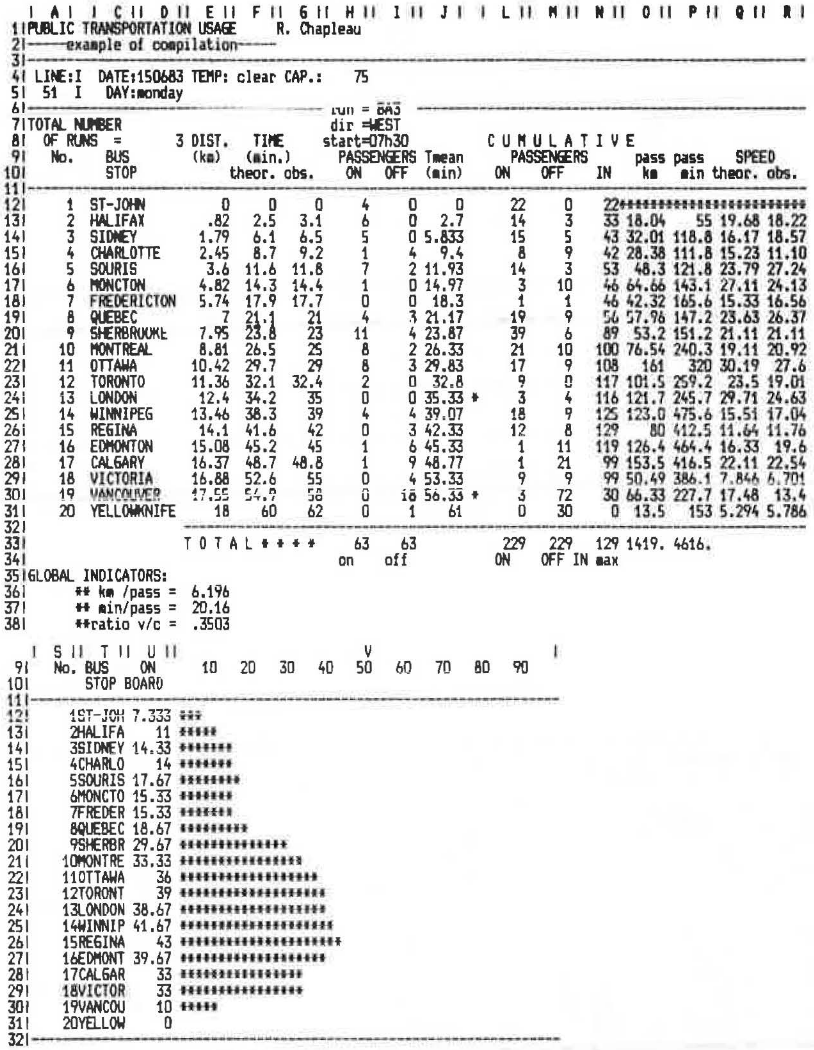
```
 | A |  | C || D || E || F || G || H ||  I |
PUBLIC TRANSPORTATION USAGE     R. Chapleau
-----example of compilation-----
-----------------------------------------------
 LINE:I  DATE:150683 TEMP: clear CAP.:     75
  51  I    DAY:monday
------------------------------------ run = BA3
TOTAL NUMBER                          dir =WEST
  OF RUNS  =         3 DIST.  TIME   start=07h30
   No.      BUS       (km)  (min.)     PASSENGERS
            STOP           theor. obs.   ON   OFF
-----------------------------------------------
       1  ST-JOHN        0     0     0    4     0
       2  HALIFAX      .82   2.5   3.1    6     0
       3  SIDNEY      1.79   6.1   6.5    5     0
       4  CHARLOTTE   2.45   8.7   9.2    1     4
       5  SOURIS       3.6  11.6  11.8    7     2
       6  MONCTON     4.82  14.3  14.4    1     0
       7  FREDERICTON 5.74  17.9  17.7    0     0
       8  QUEBEC         7  21.1    21    4     3
       9  SHERBROOKE  7.95  23.8    23   11     4
      10  MONTREAL    8.81  26.5    25    8     2
      11  OTTAWA     10.42  29.7    29    8     3
      12  TORONTO    11.36  32.1  32.4    2     0
      13  LONDON      12.4  34.2    35    0     0
      14  WINNIPEG   13.46  38.3    39    4     4
      15  REGINA      14.1  41.6    42    0     3
      16  EDMONTON   15.08  45.2    45    1     6
      17  CALGARY    16.37  48.7  48.8    1     9
      18  VICTORIA   16.88  52.6    55    0     4
      19  VANCOUVER  17.55  54.9    58    0    18
      20  YELLOWKNIFE   18    60    62    0     1
                                   ------------
                                         63    63
```

FIGURE 6 Observations of three bus runs on Line 51.

```
   | A |  | C || D || E || F || G || H || I || J |  | L || M || N || O || P || Q || R |
 1|PUBLIC TRANSPORTATION USAGE     R. Chapleau
 2|-----example of compilation-----
 3|------------------------------------------------------------------------------------
 4| LINE:I  DATE:150683 TEMP: clear CAP.:     75
 5|  51  I    DAY:monday
 6|---------------------------- run = BA1  -------------------------------------------
 7|TOTAL NUMBER                  dir =WEST
 8|  OF RUNS  =        1 DIST.  TIME   start=07h00        C U M U L A T I V E
 9|   No.     BUS       (km)  (min.)     PASSENGERS Tmean     PASSENGERS      pass pass    SPEED
10|           STOP          theor. obs.   ON   OFF  (min)    ON    OFF    IN   km   min theor. obs.
11|------------------------------------------------------------------------------------
12|      1  ST-JOHN        0     0     0   10     0     0     10     0    10************************
13|      2  HALIFAX      .82   2.5     3    5     2     3      5     2    13   8.2    25 19.68  16.4
14|      3  SIDNEY      1.79   6.1     6    5     2     6      5     2    16 12.61  46.8 16.17  19.4
15|      4  CHARLOTTE   2.45   8.7     9    3     3     9      3     3    16 10.56  41.6 15.23  13.2
16|      5  SOURIS       3.6  11.6    12    4     0    12      4     0    20  18.4  46.4 23.79    23
17|      6  MONCTON     4.82  14.3    15    2     6    15      2     6    16  24.4    54 27.11  24.4
18|      7  FREDERICTON 5.74  17.9    18    0     1    18      0     1    15 14.72  57.6 15.33  18.4
19|      8  QUEBEC         7  21.1    21    7     2    21      7     2    20  18.9    48 23.63  25.2
20|      9  SHERBROOKE  7.95  23.8    24   12     0    24     12     0    32    19    54 21.11    19
21|     10  MONTREAL    8.81  26.5    27    8     3    27      8     3    37 27.52  86.4 19.11  17.2
22|     11  OTTAWA     10.42  29.7    30    5     2    30      5     2    40 59.57 118.4 30.19  32.2
23|     12  TORONTO    11.36  32.1    33    4     0    33      4     0    44  37.6    96  23.5  18.8
24|     13  LONDON      12.4  34.2    36    1     1    36 *    1     1    44 45.76  92.4 29.71  20.8
25|     14  WINNIPEG   13.46  38.3    39    6     0    39      6     0    50 46.64 180.4 15.51  21.2
26|     15  REGINA      14.1  41.6    42    8     2    42      8     2    56    32   165 11.64  12.8
27|     16  EDMONTON   15.08  45.2    45    0     0    45      0     0    56 54.88 201.6 16.33  19.6
28|     17  CALGARY    16.37  48.7    48    0     4    48      0     4    52 72.24   196 22.11  25.8
29|     18  VICTORIA   16.88  52.6    51    7     0    51 *    7     0    59 26.52 202.8 7.846  10.2
30|     19  VANCOUVER  17.55  54.9    54    1    33    54      1    33    27 39.53 135.7 17.48  13.4
31|     20  YELLOWKNIFE   18    60    60    0    27    60      0    27     0 12.15 137.7 5.294   4.5
32|                    --------------------------------------------------------------
33|                    T O T A L * * * *   88    88           88    88    59 581.2 1986.
34|                                        on   off           ON    OFF IN max
35|GLOBAL INDICATORS:
36|       ** km /pass =  6.605
37|       ** min/pass =  22.57
38|       **ratio v/c =  .4305

   | S || T || U ||                   V          |
 9|  No. BUS    ON     10   20   30   40   50   60   70   80   90
10|      STOP BOARD
11|-----------------------------------------------------------------
12|     1ST-JOH   10 *****
13|     2HALIFA   13 ******
14|     3SIDNEY   16 ********
15|     4CHARLO   16 ********
16|     5SOURIS   20 **********
17|     6MONCTO   16 ********
18|     7FREDER   15 *******
19|     8QUEBEC   20 **********
20|     9SHERBR   32 ****************
21|    10MONTRE   37 ******************
22|    11OTTAWA   40 ********************
23|    12TORONT   44 **********************
24|    13LONDON   44 **********************
25|    14WINNIP   50 *************************
26|    15REGINA   56 ****************************
27|    16EDMONT   56 ****************************
28|    17CALGAR   52 **************************
29|    18VICTOR   59 *****************************
30|    19VANCOU   27 *************
31|    20YELLOW    0
32|-----------------------------------------------------------------
```

FIGURE 7 Report of bus run BA1 on Line 51.



```
   I  A I  I  C II  D II  E II  F II  6 II  H II  I II  J I  I  L II  M II  N II  O II  P II  Q II  R I
 1 IPUBLIC TRANSPORTATION USAGE     R. Chapleau
 2 I-----example of compilation-----
 3 I------------------------------------------------------------------------------------------------
 4 I LINE:I  DATE:150683 TEMP: clear CAP.:     75
 5 I  51  I   DAY:monday
 6 I------------------------------------ run = 8A3 ---------------------------------------------
 7 ITOTAL NUMBER                         dir =WEST
 8 I  OF RUNS  =        3 DIST.   TIME   start=07h30          C U M U L A T I V E
 9 I   No.     BUS        (km)    (min.)     PASSENGERS Tmean     PASSENGERS       pass pass    SPEED
10 I           STOP           theor. obs.    ON    OFF  (min)    ON     OFF    IN    km   min theor. obs.
11 I------------------------------------------------------------------------------------------------
12 I     1  ST-JOHN         0     0     0    4      0     0     22      0     22**************************
13 I     2  HALIFAX       .82   2.5   3.1    6      0   2.7     14      3     33 18.04    55 19.68 18.22
14 I     3  SIDNEY       1.79   6.1   6.5    5      0 5.833     15      5     43 32.01 118.8 16.17 18.57
15 I     4  CHARLOTTE    2.45   8.7   9.2    1      4   9.4      8      9     42 28.38 111.8 15.23 11.10
16 I     5  SOURIS        3.6  11.6  11.8    7      2 11.93     14      3     53  48.3 121.8 23.79 27.24
17 I     6  MONCTON      4.82  14.3  14.4    1      0 14.97      3     10     46 64.66 143.1 27.11 24.13
18 I     7  FREDERICTON  5.74  17.9  17.7    0      0  18.3      1      1     46 42.32 165.6 15.33 16.56
19 I     8  QUEBEC          7  21.1    21    4      3 21.17     19      9     56 57.96 147.2 23.63 26.37
20 I     9  SHERBROOKE   7.95  23.8    23   11      4 23.87     39      6     89  53.2 151.2 21.11 21.11
21 I    10  MONTREAL     8.81  26.5    25    8      2 26.33     21     10    100 76.54 240.3 19.11 20.92
22 I    11  OTTAWA      10.42  29.7    29    8      3 29.83     17      9    108   161   320 30.19  27.6
23 I    12  TORONTO     11.36  32.1  32.4    2      0  32.8      9      0    117 101.5 259.2  23.5 19.01
24 I    13  LONDON       12.4  34.2    35    0      0 35.33 *    3      4    116 121.7 245.7 29.71 24.63
25 I    14  WINNIPEG    13.46  38.3    39    4      4 39.07     18      9    125 123.0 475.6 15.51 17.04
26 I    15  REGINA       14.1  41.6    42    0      3 42.33     12      8    129    80 412.5 11.64 11.76
27 I    16  EDMONTON    15.08  45.2    45    1      6 45.33      1     11    119 126.4 464.4 16.33  19.6
28 I    17  CALGARY     16.37  48.7  48.8    1      9 48.77      1     21     99 153.5 416.5 22.11 22.54
29 I    18  VICTORIA    16.88  52.6    55    0      4 53.33      9      9     99 50.49 386.1 7.846 6.701
30 I    19  VANCOUVER   17.55  54.7    58    0     18 56.33 *    3     72     30 66.33 227.7 17.48  13.4
31 I    20  YELLOWKNIFE    18    60    62    0      1    61      0     30      0  13.5   153 5.294 5.786
32 I                 ------------------------------------------------------------------------------
33 I                 T O T A L * * * *   63     63            229    229    129 1419. 4616.
34 I                                     on    off             ON    OFF IN max
35 IGLOBAL INDICATORS:
36 I       ** km /pass =  6.196
37 I       ** min/pass =  20.16
38 I       **ratio v/c =  .3503

   I  S II  T II  U II                 V                        I
 9 I   No. BUS     ON     10   20   30   40   50   60   70   80   90
10 I       STOP BOARD
11 I---------------------------------------------------------------------
12 I      1ST-JOH 7.333 ***
13 I      2HALIFA    11 *****
14 I      3SIDNEY 14.33 *******
15 I      4CHARLO    14 *******
16 I      5SOURIS 17.67 ********
17 I      6MONCTO 15.33 *******
18 I      7FREDER 15.33 *******
19 I      8QUEBEC 18.67 *********
20 I      9SHERBR 29.67 **************
21 I     10MONTRE 33.33 ****************
22 I     11OTTAWA    36 ******************
23 I     12TORONT    39 *******************
24 I     13LONDON 38.67 *******************
25 I     14WINNIP 41.67 ********************
26 I     15REGINA    43 *********************
27 I     16EDMONT 39.67 *******************
28 I     17CALGAR    33 ****************
29 I     18VICTOR    33 ****************
30 I     19VANCOU    10 *****
31 I     20YELLOW     0
32 I---------------------------------------------------------------------
```

FIGURE 8 Report giving averages for three bus runs during peak hour.

not only cheap and fast but requires no special knowledge of computer programming languages. The extremely user-friendly design of these mass-produced programs that contain no "bugs" provides an easy way to introduce computers at all levels of the transportation agency. This will help to demystify computers for engineers and planners now working in the field. The ease of use of these programs encourages more frequent applications because it is possible to produce interesting results without the long and hard apprenticeship necessary to work with a mainframe computer.

REFERENCES

1. H.J. Simkowitz and M.L. Manheim. Microcomputers and Transportation Team Up: What's Ahead? TRNews, No. 105, March-April 1983, pp. 6-11.
2. Osborne 1 User's Reference Guide. Sorcim Corporation, Santa Clara, Calif., 1981.
3. Microcomputers in Transportation: Software and Source Book. UMTA-URT-41-83-1. UMTA, U.S. Department of Transportation, 1983.
4. P.C. Box et al. Manual of Traffic Engineering Studies. Institute of Transportation Engineers, Washington, D.C., 1976.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Optimal Design of Bus Routes and Frequencies for Ahmedabad

B. R. MARWAH, FAROKH S. UMRIGAR, and S. B. PATNAIK

ABSTRACT

A method is developed to simultaneously select routes and assign frequencies for a bus transit system. The method is intended (a) to concentrate the flow of passengers on the road network in such a way that the sum of passenger riding-time cost and operation cost is minimized, (b) to generate a large set of possible bus routes that satisfy certain constraints, and (c) to simultaneously select the routes and their frequencies so that the number of transfers saved in the network is maximized. Heuristics are used for the concentration of flow and generation of routes, and linear programming is used to select routes and their frequencies. The model was applied to the design of a bus transit system for the city of Ahmedabad. Four alternative networks with 514, 492, 426, and 402 links, respectively, were evaluated for the concentration of passenger flows, and the minimum cost (riding-time cost plus operation cost) was obtained for the network of 426 links. This network was used to generate 457 feasible routes. A total of 421 turning movements for the network was identified. The optimal routes and their frequencies were obtained by the linear programming model for three different operating fleet sizes of 670, 750, and 790 buses, respectively.

Ahmedabad, population 2.1 million, is the sixth largest metropolis in India and is the largest industrial city in the state of Gujarat. The city is accessible by seven major highways and five major rail links, both broad and meter gauge, from different parts of the state and the country. Because of its great accessibility, the city has grown concentrically (1). The bus transit system in the city is operated by Ahmedabad Municipal Transport Service (AMTS). AMTS operates 191 bus routes with an operating fleet of 670 buses. Approximately 0.85 million passengers per day are served by 10,600 scheduled bus trips. Average route length is 8 km (1). The transit network consists of 134 important nodes. Transit network expansion has largely been the result of sociopolitical demands in the absence of a well-defined route location policy (1,2). Increases in routes inconsistent with the fleet size have resulted in parallel operations, low load factors, and low frequencies. As a result nearly one-third of the existing routes are uneconomical.

A study of the literature on the various models of bus transit planning (3-8) indicates that the generation of routes and scheduling of vehicles are generally done sequentially. On the basis of the given desired travel matrix, the routes are first generated one at a time. Routes are evaluated without considering the routes already accepted for the network. This neglects, to a great extent, the interactions between the transit routes. The scheduling of vehicles on the routes is done after all the routes in the network have been determined.

This study has developed a method whereby the selection of routes and the assignment of frequencies are done simultaneously for the bus transit system. The method is a combination of heuristic search and programming models and has been applied in the optimal design of the bus transit network for Ahmedabad (9). The model structure is shown in Figure 1.

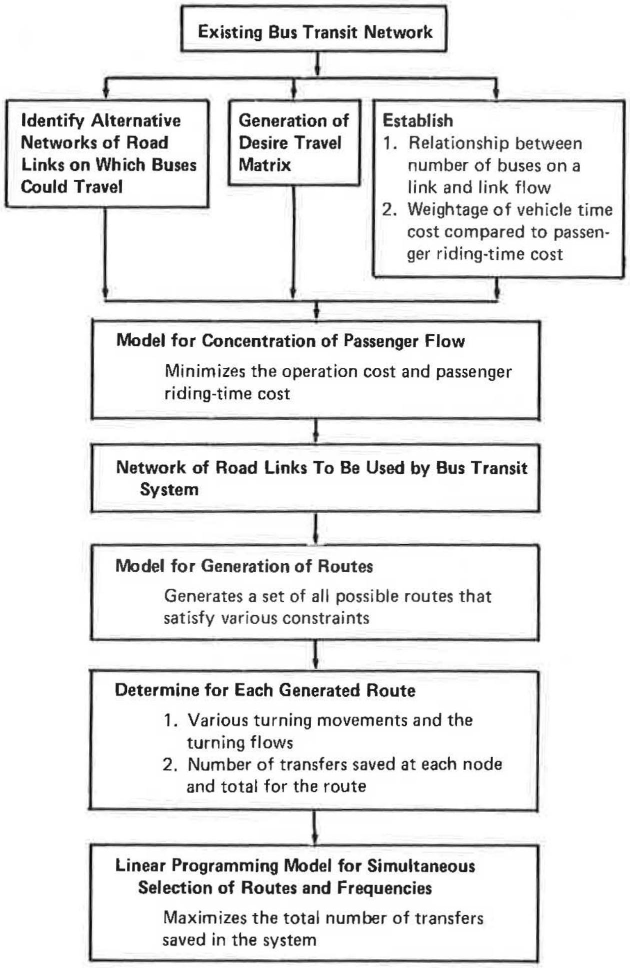


FIGURE 1 Structure of the model.

MODEL FOR CONCENTRATION OF PASSENGER FLOW

The model estimates where the passengers are expected to travel in the optimal route system. If all the passengers travel along their shortest paths, this would imply an extremely dispersed route network with low vehicle use and many vehicle hours. On the other hand if the vehicles are filled to capacity, the implication is that passengers are concentrated in large flows and thus have to make substantial detours from their shortest paths, resulting in increased riding time. To reach a reasonable compromise between these two extremes, the sum of operation cost and passenger riding-time cost is minimized for the fixed desired origin-destination (O-D) matrix.

Let RT_i be the riding time on link i and $LKFLOW_i$ the passenger flow in unit time on link i. Then the total riding time for all the passengers is $\sum_i RT_i \cdot LKFLOW_i$ and the total vehicle time for the network is $\sum_i RT_i \cdot NOBUS_i$ where $NOBUS_i$ is the number of bus trips to be made in a unit time on link i. The objective function is

$$\text{Minimize } Z_1 = \sum_i RT_i \cdot LKFLOW_i + \sum_i RT_i \cdot NOBUS_i \cdot W \quad (1)$$

subject to satisfaction of given travel demand, where W is the value of vehicle time compared to the riding time of passengers.

The number of trips to be made in a unit time on a link $NOBUS_i$ depends on the passenger flow on that link, $LKFLOW_i$. Some studies (8,10,11) indicate that $NOBUS_i$ is directly proportional to the square root of passengers on a link. In the absence of any such relationship for Indian cities, the average link flow of passengers on a route for all the 191 routes is related to the existing number of bus trips on that route as

$$NOBUS_i = 0.137 LKFLOW_i^{0.795} \qquad R^2 = 0.88 \quad (2)$$

where $NOBUS_i$ is the number of bus trips to be made in a unit time on link i and $LKFLOW_i$ is the flow of passengers in unit time on link i.

Next, to rationalize the relationship between the value of vehicle time and that of the riding time of passengers, the following equation is developed:

$$W = BUSKMH \cdot KMCOST/VT \quad (3)$$

where

W = value of vehicle time relative to that of passenger riding time,
BUSKMH = average kilometers traveled by the bus in an hour,
KMCOST = operating cost of a bus per kilometer, and
VT = value of the riding-time hours of the riders.

The operating cost (KMCOST) per bus kilometer is found by considering salaries, allowances, fuel and oil consumptions, repair and spare parts plus other overhead charges, depreciation, and so forth. The value of a riding-time hour (VT) of the passenger is found by estimating the average income of captive users. The average bus-kilometers traveled per hour (BUSKMH) is obtained from the existing data on bus speeds on various links of the network. The mean value of W as estimated as 15.

The objective function (Equation 1) can be written as

$$Z_1 = \sum RT_i \cdot LKFLOW_i + \sum RT_i \cdot 0.137 LKFLOW_i^{0.795}\, W \quad (4)$$

After substituting the values of $NOBUS_i$ and W from Equations 2 and 3, respectively, the objective function is

$$\text{Minimize } Z_1 = \sum_i LKFLOW_i \cdot RT_i \, [1 + (2.055/LKFLOW_i^{0.205})] = \sum_i LKFLOW_i \cdot T_i^* \quad (5)$$

where

$$T_i^* = RT_i \, [1 + (2.055/LKFLOW_i^{0.205})] \quad (6)$$

To obtain the minimum value of the nonlinear objective function a heuristic algorithm is used. A backward approach (i.e., deleting links from a fine-meshed network) appears to give better results than a forward approach (i.e., adding links to the minimal spanning tree). Initially, all of the 514 unidirected links on which buses can travel are taken and then the number is reduced to that of the coarse-meshed network (402 links). For this study, four networks are tested. The heuristic algorithm used for each of the four different networks to obtain total cost in terms of time is as follows:

1. The shortest paths for all the O-D pairs are obtained. In the first iteration, only riding time (RT_i) is considered, but in subsequent iterations the sum of riding and vehicle time (as revised in the subsequent steps; i.e., T_i^*) is used. Using the shortest paths, all the link flows ($LKFLOW_i$) are estimated for the given O-D matrix.
2. The time to traverse link i (T_i) is revised (T_i^*) based on the link flow ($LKFLOW_i$) using the following relationship:

$$T_i^* = (RT)_i \, [1 + (2.055/LKFLOW_i^{0.205})]$$

3. The revised time (T_i^*) obtained in Step 2 is used to find the shortest paths for all the O-D pairs, and a revised value of the link flow ($LKFLOW_i^*$) is obtained.
4. The total link time (i.e., $LT_i = T_i^* \cdot LKFLOW_i^*$) and total time for the network (i.e., $TLT = \sum_i T_i^* \cdot LKFLOW_i^*$) are computed.
5. If any link time (i.e., LT_i) or total link time (TLT) gets changed in Step 4, the procedure is repeated starting with Step 2; otherwise it is stopped.

This procedure is repeated for all four networks. It is observed that generally about four iterations need to be performed for each network to obtain the convergence of the total link time. The results (Table 1) indicate that by deleting some links from the starting network of 514 links, the total time is reduced until a certain stage is reached and then total time starts increasing. The minimum time is for the network with 426 links. This network is considered in the further analysis.

MODEL FOR GENERATION OF ROUTES

This model generates a large set of all possible routes through a heuristic algorithm that considers the following constraints to avoid the possibility of generating some unfeasible routes:

1. The length of the route should not be less than 2.0 km.
2. The path of the route between two terminating stations should not meander excessively from the shortest path. The length of the path of a route

TABLE 1 Concentration of Passenger Flows in Alternative Networks

Network No.	No. of Links in Network	Iteration 1 (total riding time in min)	2 (total riding + vehicle time in min)	3 (total riding + vehicle time in min)	4 (total riding + vehicle time in min)
1	514	11,897,919	13,704,568	13,718,200	13,720,158
2	492	11,898,220	13,705,189	13,718,554	13,720,282
3	426	11,903,306	13,723,576	13,717,526	13,717,565
4	402	11,954,794	13,773,298	13,767,130	13,773,238

should not be greater than twice the shortest distance between the termini.

3. There should not be any backtracking on the route.

In cases where there are a number of intermediate stations on the shortest path between two termini, there may be an extremely large number of alternative paths that may be formulated. It is desirable that the nodes inserted be selected rationally without leaving the combinations that satisfy the basic requirements.

The network consists of 134 nodes and there are 8,911 different O-D pairs that are to be served by the routes. To determine the terminating stations, it is desirable that the routes run through the major generators. Routes are also generated from other stations to satisfy the entire O-D matrix. In some studies (3,5,7) the routes between the major generators are fixed first, but the difficulty is that of satisfying the various requirements of a route in an optimal way. In this method the paths of the routes between closer terminals are first determined and then expanded for the distant ones. The already developed paths are of great significance in the location of the paths of the routes between the distant termini.

This is a four-step procedure:

1. All the O-D pairs that have direct links between them are first selected for route generation. Let i and j be the nodes directly connected by link i-j. Alternative paths for this route between i and j can be found by inserting the intermediate nodes (e.g., k) such that path i-k-j satisfies the requirements; namely, the length of the path i-k-j is less than twice the shortest distance between nodes i and j (Figure 2). In this way all possible intermediate nodes k (k_1, k_2, . . .) that can be inserted are analyzed.

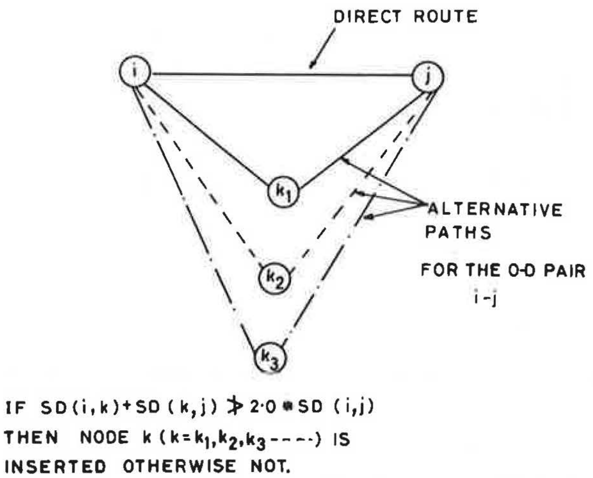


FIGURE 2 Alternative paths for directly connected O-D pair.

2. The O-D pairs, not directly connected, are divided into various groups according to the shortest distance through them. In this study, the O-D pairs are divided into nine different groups starting with 1.5 to 20 km. The generation of the routes is first done for the closer O-D pairs and then expanded by using information on previously generated routes.

3. For a given group of O-D pairs the alternative paths of the route are generated as follows: Let i-j be the O-D pair having stops i_1, i_2, i_3, . . . on the shortest path between them. Let k_1 be the node to be inserted such that the shortest path between i and j via k [i.e., SD(i,k_1) + SD(k_1,j)] is less than 1.5 times the shortest distance between i and j [SD(i,j)]. All the previously established routes between i and k_1 (i.e., R_{11}, R_{12}, R_{13}, . . .) and between k_1 and j (i.e., R_{21}, R_{22}, R_{23}, . . .) are considered (Figure 3). All the combinations of the routes between i and k_1 and k_1 and j are analyzed so that the total length of the selected path between i and j does not exceed twice the shortest distance between i and j.

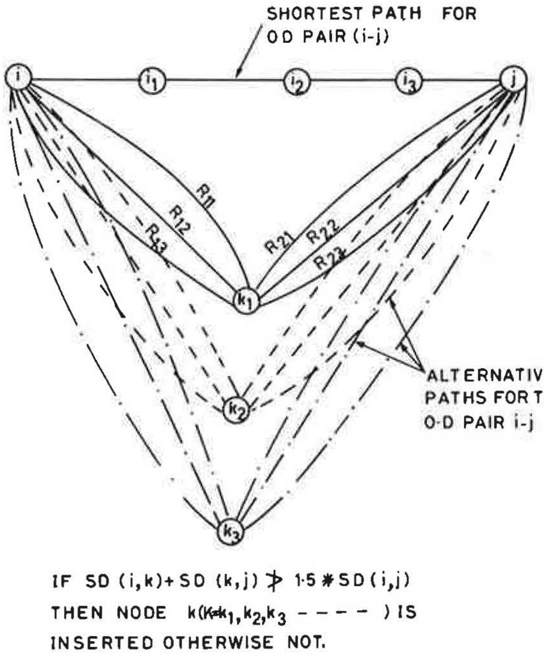


FIGURE 3 Alternative paths for O-D pair not directly connected.

The procedure is repeated for all the possible intermediate nodes (i.e., k_1, k_2, k_3, . . .) to be inserted, and all the feasible routes are stored.

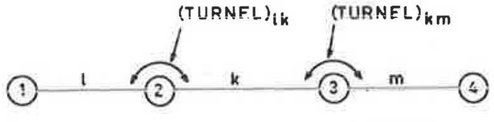
4. Step 3 is repeated for all the O-D pairs of a group.

This heuristic procedure generated 457 possible routes for the Ahmedabad network.

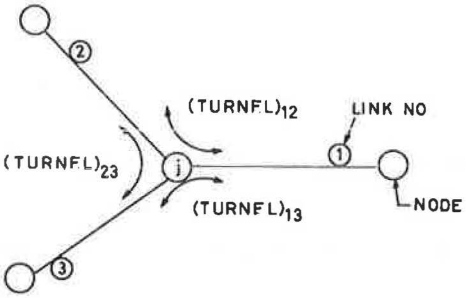
TRANSFERS SAVED

When a route diverts or terminates at a node, the passengers destined for a node not lying on the route have to transfer.

Let the path of a route be represented by nodes 1, 2, 3, and 4 and links l, k, and m as shown in Figure 4(a). Let $(TURNFL)_{lk}$ be the number of passengers going directly from link l to link k and vice versa. The various turning movements on a small network are shown in Figure 4(b). The estimated number of bus trips per day is $NOBUS_l$ on link l. If a route goes directly from link l to link k, the number of transfers saved per route trip for this route and this turning flow is estimated by the following relationship:



(a) TURNING MOVEMENTS ALONG A ROUTE



(b) TURNING MOVEMENTS AT A NODE j IN A PART OF A NETWORK

FIGURE 4 Number of transfers saved on a route.

$$NOTRAN_{pr} = [TURNFL_{lk}/\text{Minimum } (NOBUS_l, NOBUS_k)] \quad (7)$$

where

$NOTRAN_{pr}$ = number of transfers saved for pth turning flow of route r,
$TURNFL_{lk}$ = number of passengers traveling from link l to link k and vice versa, and
Minimum $(NOBUS_l, NOBUS_k)$ = minimum value of the number of bus trips on the two links l and k.

The procedure for calculating the number of transfers saved by a route trip is as follows:

1. All turning flows along the route are found using the O-D matrix.
2. The number of bus trips on each link is estimated using the relationship (Equation 2) between link flow and the number of bus trips. The link flow is found by using the O-D matrix.
3. The number of transfers saved for each turning flow per route trip is found by Equation 7.
4. The total number of transfers saved by a route $TTRAN_r$ is found by summing the transfers saved for each turning movement along the route.

This procedure was used for the case study network, and the number of transfers saved by each of the 457 routes was obtained. For each route, the transfers saved were calculated along the route and added to get the total number of transfers saved. Then all turning movements on the network were identified. The different values of the various turning movements were obtained for various routes. From these the maximum value of a turning movement was found.

For the Ahmedabad network, 421 turning movements were identified and the maximum value of each turning flow was determined.

SIMULTANEOUS CHOICE OF ROUTES AND FREQUENCIES

In the preceding phases passengers were assigned paths on the basis of passenger riding-time cost and operation cost. A set of intersecting routes (457) was generated. In this phase an optimal set of routes and frequencies is obtained such that as many transfers as possible are avoided. The problem is formulated and solved as a linear programming (LP) problem.

The objective function is

$$\text{Maximize } Z = \sum_{r=1}^{NR} TTRAN_r \cdot FREQ_r \quad (8)$$

subject to four sets of constraints

$$\sum_{i=1}^{NR} NOTRAN_{pr} \cdot FREQ_r \leq MAXTFL_p \ \forall_p \quad (9)$$

$$\sum_{i=1}^{NR} RTTIME_r \cdot FREQ_r \leq OT \cdot OPF \quad (10)$$

$$0 \leq FREQ_r \leq MAXFRE_r \ \forall_r \quad (11)$$

$$NOTRAN_p \geq 0 \ \forall_p \quad (12)$$

where

$NOTRAN_{pr}$ = number of transfers saved for pth turning flow of route r,
$FREQ_r$ = frequency on route r,
$TTRAN_r$ = total number of transfers saved by route r,
NR = number of routes in a network,
$MAXTFL_p$ = maximum value of the turning flow for the pth turning movement,
$RTTIME_r$ = round-trip time on route r,
$MAXFRE_r$ = maximum frequency of route r,
$NOTRAN_p$ = number of transfers saved for pth turning flow,
OPF = operating fleet size, and
OT = operating time in hours.

The first constraint set (Equation 9) contains TTF equations where TTF is the total number of turning moments in the network. The different values of the pth turning movement are obtained for various routes. From these, the maximum value of the pth turning movement ($MAXTFL_p$) is found and no more than this number of transfers can be saved. The second constraint set (Equation 10) takes into consideration the operating fleet size. The third constraint set (Equation 11) takes into consideration the upper boundary on frequency for every route. The fourth constraint set (Equation 12) considers the non-negativity requirements of the number of transfers saved for the pth turning movement.

ANALYSIS OF RESULTS

For the fixed O-D matrix of Ahmedabad, the model generates 426 links on the network on which the passenger flow can be concentrated to minimize the total cost (riding-time cost plus vehicle operation cost). The network consisting of these 426 links (213 links in each direction) and 134 nodes is used to generate the feasible routes that satisfy the basic requirements of the routes and meet the demand. A total of 457 routes is generated and 421 turning movements are identified. The optimal routes and their frequencies are obtained for seven different zones and for the entire network using three different operating fleets of 670, 750, and 790 buses. A summary of the outputs is given in Tables 2 and 3. The results indicate that the number of routes in the optimal solution, the number of transfers saved, and the average route length are affected by the size of the operating fleet for the network. Figure 5 shows that as the size of the operating fleet for the network increases, the number of routes in the optimal solution also increases. This happens because increased numbers of vehicles help run more routes and thus maximize the number of transfers saved. Figure 6 shows that more transfers are saved with increased numbers of routes or increased size of the operating fleet.

TABLE 2 Summary of Outputs for the Different Zones

Zone No.	Part of Network	Fleet Size	No. of Optimal Routes	Maximum Frequency per Day	No. of Transfers Saved
1	Central	52	8	340	235,777
		69	14	340	288,417
		88	23	333	323,074
2	West	102	35	120	316,841
		114	35	120	316,841
		117	35	120	316,841
3	North	154	34	111	334,631
		166	34	111	334,631
		172	34	111	334,631
4	Southeast	99	35	224	354,924
		110	43	223	358,692
		114	43	223	358,692
5	East	64	16	141	200,665
		72	30	123	230,307
		74	30	123	230,307
6	Northeast	114	32	170	339,228
		125	32	170	339,228
		129	32	170	339,228
7	South and southwest	85	26	192	269,310
		94	28	192	270,043
		96	28	192	270,043

TABLE 3 Summary of Outputs for the Network

	Total Fleet Size		
	670	750	790
No. of optimal routes	160	191	207
Average route length (km)	6.625	6.11	5.8
No. of transfers saved (10^3)	2,052	2,138	2,173

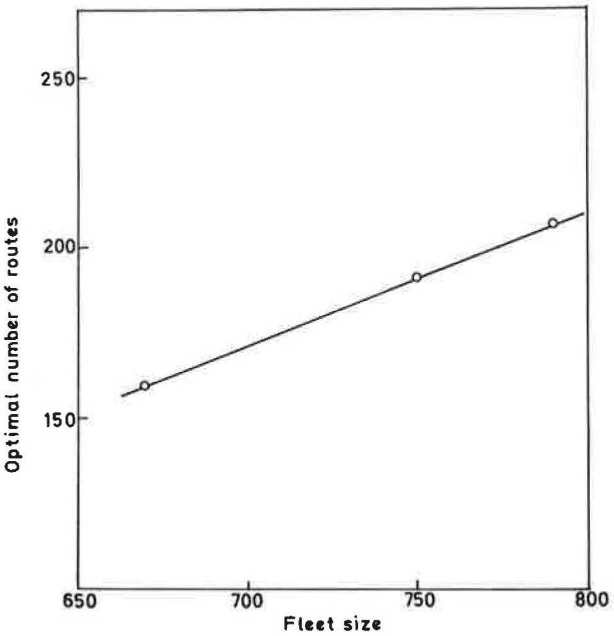


FIGURE 5 Relationship between optimal number of routes and fleet size for the network.

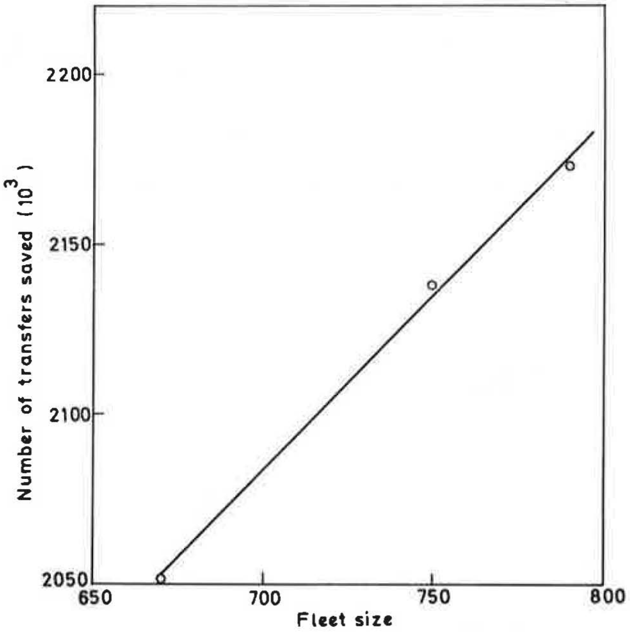


FIGURE 6 Relationship between number of transfers saved and fleet size for the network.

As the number of routes in the optimal solution increases, the tendency is to have shorter routes. Figure 7 shows that the average length of the route decreases with fleet size. The length of routes varies between 2.0 and 20.0 km with a mean of 6.625 km for an operating fleet of 670.

The data given in Table 2 indicate that the effect of operating fleet size on the routing system for a zone depends on the size, the traffic demand, and the land-use pattern of the zone. The central zone, which is quite small in area compared to other zones, has been found to be quite sensitive to changes in fleet size compared to other zones. The optimal routes with their paths obtained for the central zone for a fleet of 88 buses are shown in

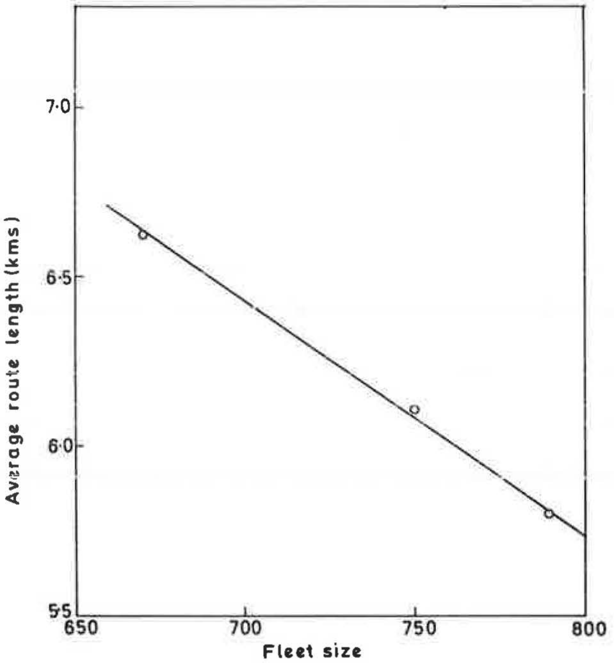


FIGURE 7 Relationship between average route length and fleet size for the network.

Figure 8. When the fleet size is changed from 52 to 88 vehicles, the number of routes in the optimal solution increases from 8 to 23. The maximum frequency of a route in a zone depends on travel demand. The data in Table 2 indicate that the maximum frequency is insensitive to the range of the operating fleet sizes considered in this experiment.

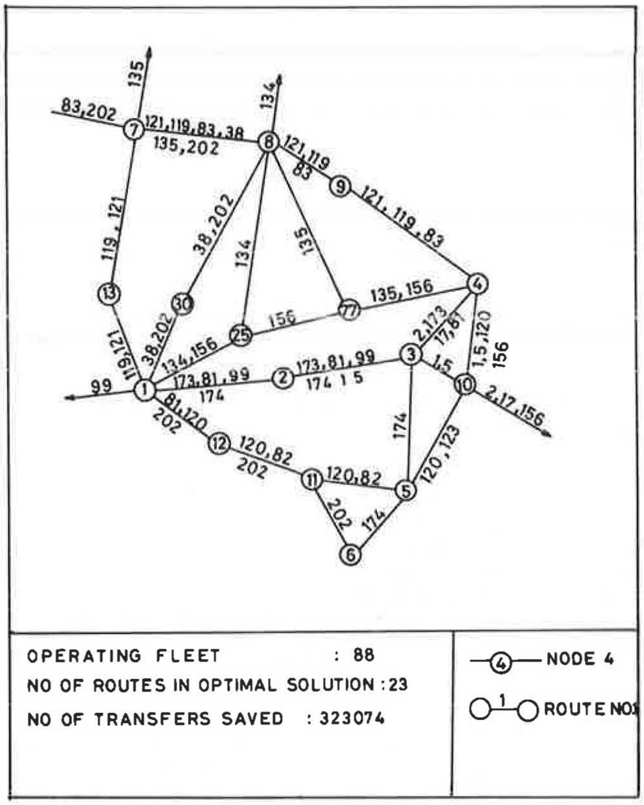


FIGURE 8 Route network for Central Zone (operating fleet = 88).

CONCLUSIONS

The proposed method is a valuable tool for simultaneous selection of optimal routes and frequencies for a bus transit network. It can be used by the planner to structure routes in a rational and systematic way for the given spatial distribution of travel demand, and to find the number of buses and frequencies on each route and the operating fleet size for the system.

On the basis of the application of the model to the city of Ahmedabad, the following conclusions can be drawn:

1. The number of bus trips (Y) on a link for a day varies with the passenger flow (X) on the link. The relationship has been established for the city of Ahmedabad and is of the form $Y = aX^b$.
2. For a given spatial distribution of travel demand, the optimal total cost (passenger riding-time cost plus operation cost) can be obtained from the algorithm that concentrates the flow on the links.
3. The method first distributes the passengers on the links in the network and then generates routes that follow the passengers. This method is computationally efficient compared with other methods that repeatedly distribute the passengers on trial networks.
4. The route-generating procedure developed in this study is a systematic and rational algorithm that generates a large set of all possible routes that satisfy the various requirements.
5. Selection of the optimal set of routes and frequencies is made through a linear programming formulation that maximizes the number of transfers saved on the network. This method is realistic because the interaction of various routes is taken into consideration.
6. The application of the model to the city of Ahmedabad indicates that the model can be successfully applied to large transit networks, and the results are quite encouraging.
7. The results indicate that the number of routes in the optimal solution and the number of transfers saved increase linearly with an increase in operating fleet size. However, the average length of the route decreases with an increase in operating fleet size.

Future work may include consideration of the following aspects of the problem: (a) The structuring of routes and the assignment of frequencies is done for a given desired trip matrix. Further refinement of the suggested model may consider stochastic variations in travel demand. (b) The frequencies assigned are for the entire day. The variation of headways during the day needs to be investigated. (c) Operation cost and passenger riding-time cost have been considered in terms of time by estimating their weights. The analysis can be made more realistic by considering actual costs.

REFERENCES

1. Report on Ahmedabad Urban Transport Project. Ahmedabad Municipal Transport Service, Ahmedabad, Gujarat, India, 1979.
2. Urban Transport, A Sector Policy Paper. World Bank, Washington, D.C., May 1976.
3. S.L. Dhingra. Simulation of Routing and Scheduling of City Bus Transit Network. Ph.D. thesis. IIT Kanpur, India, May 1980.
4. J. Hsu and V.H. Surti. A System Approach of Optimal Bus Network Design. Research Report 19.

Center for Urban Transportation Studies, University of Colorado at Denver, Sept. 1975.

5. W. Lampkin and P.D. Saalmans. The Design of Routes, Service Frequencies, and Scheduling for a Municipal Bus Undertaking: A Case Study. Operational Research Quarterly, Vol. 18, No. 4, 1967.
6. A. Last and S.E. Leak. Transport: A Bus Model. Traffic Engineering and Control, Vol. 17, No. 1, Jan. 1976.
7. A.H. Lines, W. Lampkin, and P.D. Saalmans. The Design of Routes and Service Frequencies for a Municipal Bus Company. Proc., Fourth International Symposium on Operational Research, Boston, Mass., 1966.
8. J.C. Rea. Designing Urban Transit Systems: An Approach to the Route-Technology Selection Problem. NTIS-PB-204881. Washington University, Seattle, 1971.
9. F.S. Umrigar. Modelling for Simultaneous Selection of Optimal Bus Routes and Their Frequencies--A Case Study for Ahmedabad. M.Tech. thesis. IIT Kanpur, India, May 1982.
10. A. Scott. The Optimal Network Problem: Some Computational Procedures. Transportation Research, Vol. 3, 1969, pp. 201-210.
11. D. Hasselstorm. A Method for Optimization of Urban Bus Route Systems. Publication 88-DH-03. Volvo Bus Corporation, Gothenburg, Sweden, 1979.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Reducing the Energy Requirements of Suburban Transit Services by Route and Schedule Redesign

N. JANARTHANAN and J. SCHNEIDER

ABSTRACT

Reducing energy consumption has become an increasingly important concern of transit planners and managers in recent years. Energy consumption may be reduced by improved scheduling of vehicles, reduced deadheading, and laying out more efficient routes. This paper investigates several ways of redesigning an existing transit service to reduce its energy requirements without reducing service quality substantially. Bellevue, a suburban area within King County, Washington, is used as the study area in this investigation. A 13-route existing transit service in Bellevue is simulated and then redesigned to reduce its energy requirements while still providing a comparable level of service. The generation and evaluation of seven alternate designs was accomplished with an interactive graphic computer program called the Transit Network Optimization Program. Results from the "best" design indicate that the energy requirements of the existing system could be reduced by about 56 percent without a substantial reduction of the level and quality of service in the study area.

Most transit agencies are currently under substantial financial pressure and depend heavily on governmental aid to meet many of their operating costs. Consequently, cost reduction techniques, particularly those that relate to energy costs, are receiving more attention. In recent years energy costs have become a fast-growing and large component of operating costs. Because of fluctuating prices and uncertainty about availability, reducing energy consumption has become an important concern of both planners and managers of transit systems. Energy consumption may be reduced by improving the scheduling of vehicles, reducing deadheading, and laying out more efficient routes. The optimal scheduling of vehicles is constrained by minimum headway requirements and deadheading by the location of bus bases. Transit routes may often be shifted to some limited extent to save energy. The objective of this study is to determine how much energy might be saved by designing more energy-efficient route structures and schedules. An interactive graphic computer program, the Transit Network Optimization Program (TNOP), is used to generate and evaluate alternative designs quickly and easily.

TNOP can be used to design and evaluate the performance of alternative fixed-route, fixed-schedule bus and rail transit systems. Through interactive computing, TNOP helps transit planners generate and evaluate a wide range of design alternatives and to compare their performance characteristics. Typically, planners are able to find higher performance designs by providing transit services that more closely match actual origin-destination travel patterns. Seattle Metro Transit decided to explore the applicability of TNOP to this question and this study was designed to evaluate TNOP's usefulness as a planning tool for the transit industry. Initially TNOP was used to simulate the existing transit service in the study area. Then a search for alternative designs that were more energy efficient but still gave high performance was conducted.

DESCRIPTION OF STUDY AREA

The area chosen for this study is the city of Bellevue, located in a suburban area of King County, Washington. Bellevue is located between Lake Washington and Lake Sammamish, about 6 miles east of Seattle (Figure 1) (1,pp.1-41). The city of Bellevue has the second largest population in urban King County and is the fourth largest city in Washington State. It has an area of 24.5 square miles. Bellevue is a major employment center for the Puget Sound region. It is also a major commercial center that is well linked to established transportation corridors.

Bellevue had a total population of 73,711 in 1980 and has had an average annual growth rate of 3.5 percent. The median family income is $24,000 (1978), which is higher than the King County average. The total number of people employed in the city was 41,000 in 1980, which is more than the number of workers who reside within its corporate limits. This area is reasonably well served by bus transit.

DATA PREPARATION

The data base for TNOP consists primarily of a base network, a demand matrix (trip table), and vehicle data (2,3).

Network Data

The development of the base network consisted of collecting land-use, economic, and existing street and highway information. From this a node-link network was developed for the study area. External nodes (nodes outside the study area) were connected to the study area network by major arterials or expressways. The Bellevue base network that resulted is shown in Figure 2. It consists of 231 nodes and 344 two-way bus links. Nodes 1 through 20 are external nodes. They are shown much closer to the study area than they actually are for map design purposes. Freeways are represented by thick dashed lines. Table 1 gives the major network nodes and the areas represented by them.

Demand Matrix

In 1982 an on-board survey was conducted by Metro in Bellevue. The survey was limited to 13 routes that either originate in or pass through downtown Bellevue. A total of 3,173 self-administered questionnaires was distributed to all bus riders during 173 inbound trips on Eastside routes and 31 trips on two van routes. Information about the origins and destinations of the trips was coded to 180 geographic zones.

Transformation of the demand matrix from a 180-zone system to a TNOP zone system was carried out (4). Using this information, an origin-destination (O-D) matrix (trip table) in TNOP format was constructed for use in this study.

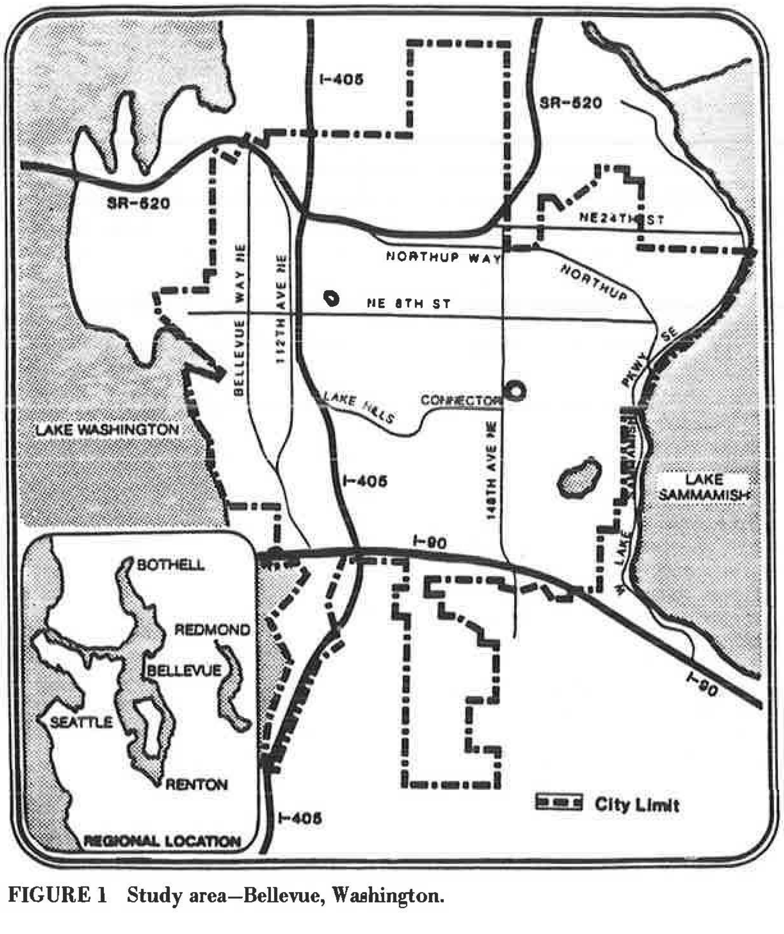


FIGURE 1 Study area—Bellevue, Washington.

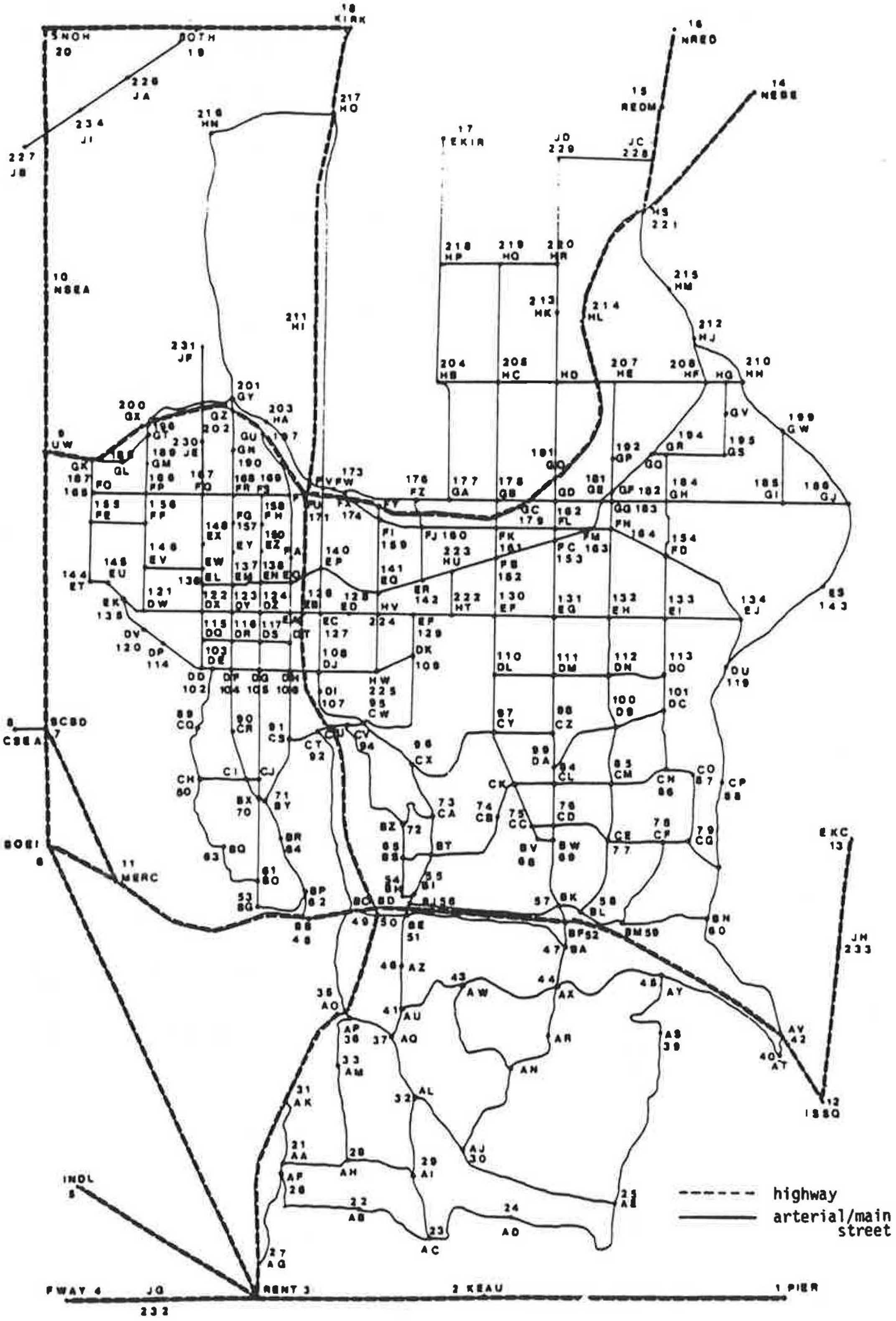


FIGURE 2 Bellevue network.

Vehicle Data

The vehicle data include information about the different types of vehicles available for use, their capacity, and their operating costs (per kilometer and per hour).

All the data prepared for the study area were verified before proceeding to the design work. The base network was verified by plotting it and comparing it with the map used for digitization. The demand matrix was verified by using the desire line option of TNOP for several well-known nodes. This procedure was also assisted by generating and examining maps of the productions or attractions. These

TABLE 1 Important Bellevue Network Nodes

Node No.	Node Name (TNOP Code)	Area Represented
1	PIER	Pierce County
2	KEAU	Kent and Auburn
3	RENT	Renton
4	FWAY	Federal Way
5	INDL	Industrial Area
6	BOEI	Boeing
7	SCBD	Seattle CBD
8	CSEA	Central Seattle
9	UW	University District
10	NSEA	North Seattle
11	MERC	Mercer Island
12	ISSQ	Issaquah
13	EKC	East King County
14	NEBE	Northeast of Bellevue
15	REDM	Redmond
16	NRED	North of Redmond
17	EKIR	East of Kirkland
18	KIRK	Kirkland
19	BOTH	Bothell
20	SNOH	Snohomish
57	BK	Park-and-Ride Lot
62	BP	Park-and-Ride Lot
116	DR	Bellevue Transfer Center
191	GS	Park-and-Ride Lot

graphics help the planner check the reasonableness and validity of the data.

CALIBRATION OF LINK TRAVEL TIME

In many cases there may not be enough data about the actual time on the links. It is important to have correct link travel times because they influence the assignment process and therefore the load on each transit line. For this study actual link travel times were not available, so the link file was constructed with posted speeds. An existing Metro route was designed on the network and the travel time was calculated using TNOP. This travel time was compared with the actual Metro schedule. The same procedure was repeated for many routes. An average factor was derived from this procedure that was used to convert actual into TNOP travel times. Using this factor, the link file was modified to incorporate the more realistic travel times.

METHODOLOGY

The methodology used for the energy efficiency study consists of the following steps:

Step 1: Simulate the operation of the existing 13 routes included in the Metro survey.

Step 2: Evaluate the design representing the existing system. Some of the measures to be checked on are (a) number of unassigned trips, (b) average use, (c) total route length, (d) total vehicle-kilometers, (e) average total trip time, (f) average total wait time, (g) average total transfer time, (h) average total walk time, (i) number of transfers, and (j) total operating costs per hour.

Step 3: If any of the measures do not reflect the true condition of the existing system, the cause must be ascertained and corrections made before going to the next step.

Step 4: Study the weaknesses of the existing system--for example, too many lines covering a route, many long routes, or inadequate connection to main nodes. Try to match the productions and attractions using trip desire line graphics. Check the line capacity provided and the loadings on the lines. See if there is excess line capacity available.

Step 5: Sketch the new route system over the network on a sheet of paper. Try to cover all the important O-D nodes. Define the lines for computer input and assign the trips.

Step 6: Evaluate the new design using the measures discussed previously. The number of trips unassigned may be equal to or less than those of the existing system. If the number of unassigned trips is more, the new system does not serve all the nodes served by the existing system. The design has to be modified until the objective is reached. The design also has to meet the headway and other con- straints present in the existing system.

Step 7: There is no direct way to calculate the energy used by the transit service in a TNOP design. The energy can, however, be calculated from the total number of vehicle-kilometers. In many cases the average total trip time, wait time, transfer times, and number of transfers may be higher in the proposed design than in the existing system. The amount by which they may exceed present levels depends on the objectives.

ANALYSIS

In this section the analysis and the results of the energy-efficiency study are presented. A total of seven alternative designs was developed. The existing and the proposed system of routes are discussed in the following sections.

Existing System

The existing system has 13 routes, which were surveyed by Metro. These routes were simulated using TNOP. The base network used in this design is shown in Figure 3. A graphic overview of all lines is shown in Figure 4. The overview statistics for this design are given in Table 2. The total route length is 387 km (242 miles). Nineteen of 549 trips are not assigned. This may be due to rounding off errors because assignment messages did not indicate any unassigned trips. The average use of this design is only 6.9 percent, which is due to the high frequency of buses used in spite of the low demand. Table 3 gives transit line statistics. The headways used in this design are the actual headways used in the morning peak period in the existing system. Other statistics, such as average total trip time and wait time, appear to be reasonable. The total operating cost per hour is $5,683. Note that line 8 of Table 3 has an asterisk, denoting that maximum loading on one of the links on the route exceeds the total capacity by seven passengers. In all other cases the total capacity is more than the maximum loading. This is one of the reasons for the low average use. The only data available to validate the simulation of the existing network were travel times between transfer stops and the total demand using the routes. These were examined and it was found that the simulated values matched the observed values well.

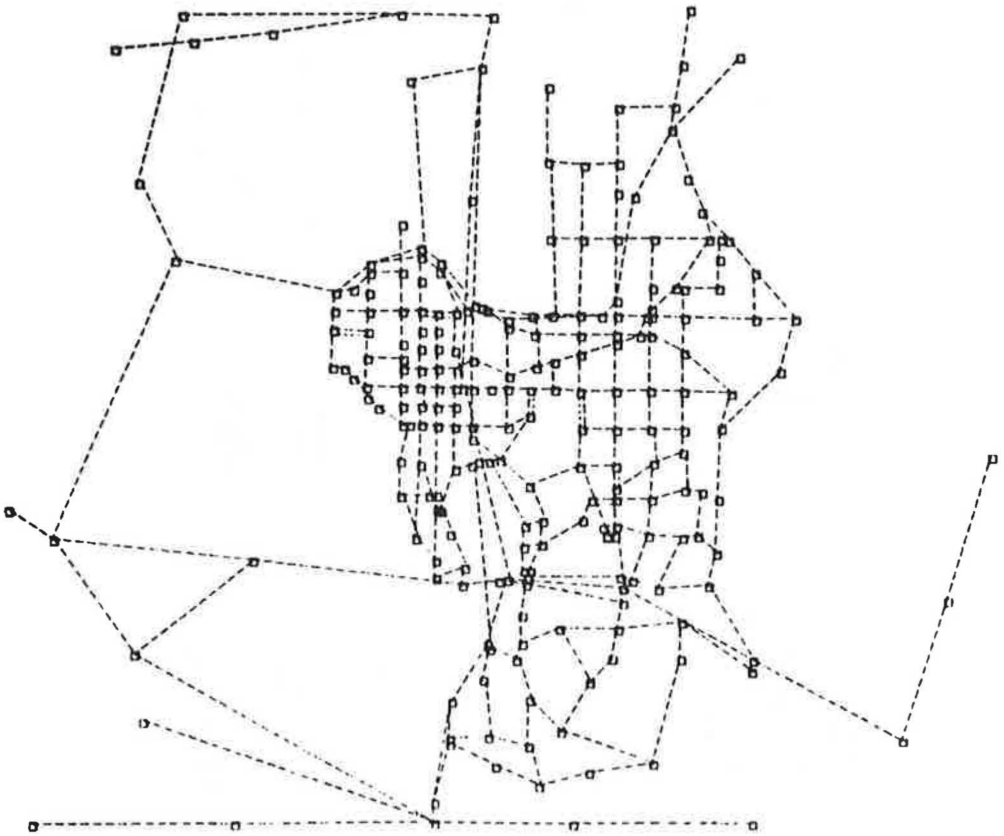


FIGURE 3 Base network (design 200).

Proposed Energy-Efficient Design

In this section the proposed energy-efficient system of routes, which will satisfy all the demand in the system but will reduce the operating costs with the least increase in total travel time and number of transfers, is presented. Six designs were generated before the final design was reached. The TNOP design numbers are 300 through 800. Designs 300 to 500 are preliminary designs. Design 600 is the proposed design. Designs 700 and 800 are extensions of design 600.

The main weaknesses of the existing system were identified before the new network was designed, and

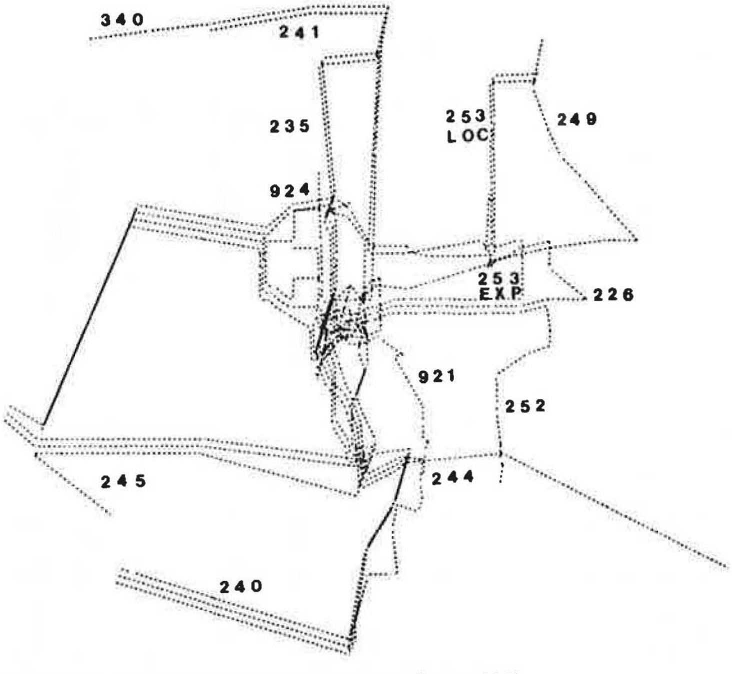


FIGURE 4 Graphic overview of bus lines (design 200).

TABLE 2 Overview Statistics (Design 200)

```
DESIGN                                                   200

NO.OF LINES: RAIL                                          0
             BUS                                          13
             TOTAL                                        13

ROUTE LENGTH:RAIL                                          0   (KM )
             BUS                                         387   (KM )
             TOTAL                                       387   (KM )

TOTAL TRIP DEMAND                                        549.
NO. OF ASSIGNED TRIPS                                    530.
NO. OF UNASSIGNED TRIPS                                   19.

AVERAGE SEATING & STANDING ROOM UTILIZATION:RAIL         0.0   ( % )
                                            BUS          6.9   ( % )
                                            TOTAL        6.9   ( % )

PASS.-KM (=SUM OF TRIP LENGTHS)                         9000.
PASS.-HRS (=SUM OF TRIP TIMES)                           420.

AV. TOTAL TRIP TIME                                     40.8   (MIN)
AV. TOTAL WAIT TIME                                      6.0   (MIN)
AV. TOTAL TRANSFER TIME                                  0.3   (MIN)
AV. TOTAL WALK TIME                                      0.5   (MIN)
AV. TOTAL TRAVEL TIME                                   47.6   (MIN)

 NO. OF TRANSFERS                                        160.
```

VEHICLE REQUIREMENTS AND OPERATING COSTS

DESIGN 200

VEHICLE TYPE	NUMBER	VEH.KM	COST/KM	COST/H	OP.COST/H
TOTAL RAIL VEHICLES	0	0			0.
VAN	4	42	1.83	44.00	253.
40-FOOT BUS	85	1725	0.98	44.00	5430.
TOTAL BUS VEHICLES	89	1767			5683.
TOTAL VEHICLES	89	1767			5683.

they are as follows: (a) overlapping of routes, (b) extremely long routes, and (c) too much line capacity compared to the demand.

The proposed system was aimed at reducing vehicle-kilometers by avoiding overlapping routes. Transfer points were created at important locations, such as downtown Bellevue and the Eastlake and Overlake park-and-ride lots. These transfer stops were connected to each other and to all important origins and destinations.

Preliminary designs 300 and 400 had a system of 10 routes with different structures. Design 300 assigned 93 percent of trips with 550 transfers, and design 400 assigned 95 percent of trips with 560 transfers. Design 500, which incorporated improvements to designs 300 and 400, assigned 97 percent of trips with 490 transfers. Figure 5 shows the routes of design 500. The overview statistics of design 500 are given in Tables 4 and 5. Table 6 gives a comparison of four designs (200 through 500). Note that in design 500 vehicle requirements have been reduced by more than 50 percent compared to design 200 (existing system), but the number of transfers and the average total trip time have increased considerably.

TABLE 3 Transit Line Statistics (Design 200)

DESIGN 200

LINE	VEH.TYPE	NUMBER VEH'S	ROUTE LENGTH	ROUTE TIME	HEAD-WAY	OPERATING COSTS/HR
1	40-FOOT BUS	7	61800	152	25	453
2	40-FOOT BUS	9	75580	177	25	573
3	40-FOOT BUS	6	61000	168	35	367
4	40-FOOT BUS	4	91800	201	60	266
5	40-FOOT BUS	3	56580	120	60	188
6	40-FOOT BUS	3	58900	124	60	190
7	40-FOOT BUS	4	31840	93	30	239
8	40-FOOT BUS	3	42800	117	45	188
9	40-FOOT BUS	6	62140	137	30	386
10	40-FOOT BUS	30	61160	156	6	1920
11	40-FOOT BUS	10	113240	254	30	661
12	VAN	2	12540	47	30	134
13	VAN	2	16680	58	60	119

DESIGN 200

LINE	VEH. TYPE	HEAD-WAY	CAPACITY			LOADINGS			
			SEAT	STAND	TOTAL	MAX	AV.	UTIL.	
1	40-FOOT BUS	25	120	60	180	74	24	13.3	
2	40-FOOT BUS	25	120	60	180	23	6	3.3	
3	40-FOOT BUS	35	85	43	128	8	2	1.6	
4	40-FOOT BUS	60	50	25	75	17	3	4.0	
5	40-FOOT BUS	60	50	25	75	31	13	17.3	
6	40-FOOT BUS	60	50	25	75	33	10	13.3	
7	40-FOOT BUS	30	100	50	150	41	19	12.7	
8	40-FOOT BUS	45	66	34	100	107	41	41.0	*
9	40-FOOT BUS	30	100	50	150	16	5	3.3	
10	40-FOOT BUS	6	500	250	750	97	27	3.6	
11	40-FOOT BUS	30	100	50	150	31	7	4.7	
12	VAN	30	24	0	24	10	3	12.5	
13	VAN	60	12	0	12	9	2	16.7	

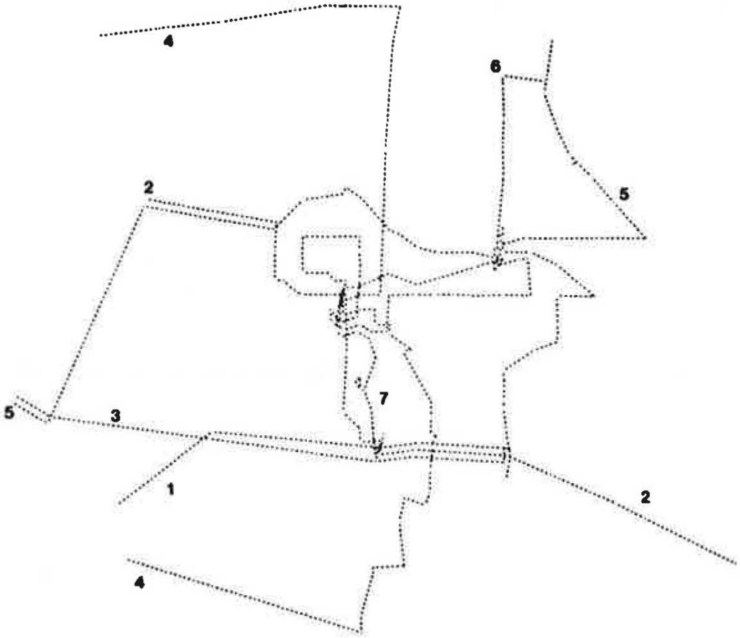


FIGURE 5 Graphic overview of bus lines (design 500).

TABLE 4 Overview Statistics (Design 500)

```
DESIGN                                                  500

NO.OF LINES: RAIL                                         0
             BUS                                          7
             TOTAL                                        7

ROUTE LENGTH:RAIL                                         0   (KM )
             BUS                                        349   (KM )
             TOTAL                                      349   (KM )

TOTAL TRIP DEMAND                                       549.
NO. OF ASSIGNED TRIPS                                   530.
NO. OF UNASSIGNED TRIPS                                  19.

AVERAGE SEATING & STANDING ROOM UTILIZATION:RAIL        0.0   ( % )
                                            BUS        16.1   ( % )
                                            TOTAL      16.1   ( % )

PASS.-KM (=SUM OF TRIP LENGTHS)                        9900.
PASS.-HRS (=SUM OF TRIP TIMES)                          510.

AV. TOTAL TRIP TIME                                    45.9   (MIN)
AV. TOTAL WAIT TIME                                     9.7   (MIN)
AV. TOTAL TRANSFER TIME                                 1.9   (MIN)
AV. TOTAL WALK TIME                                     0.5   (MIN)
AV. TOTAL TRAVEL TIME                                  58.0   (MIN)

 NO. OF TRANSFERS                                       490.

VEHICLE REQUIREMENTS AND OPERATING COSTS

DESIGN      500

VEHICLE TYPE            NUMBER    VEH.KM    COST/KM      COST/H   OP.COST/H

---------------------------------------------------------------------------
TOTAL RAIL VEHICLES          0         0                                 0.
40-FOOT BUS                 42       818       0.98       44.00       2650.
---------------------------------------------------------------------------
TOTAL BUS VEHICLES          42       818                              2650.

TOTAL VEHICLES              42       818                              2650.
```

TABLE 5 Transit Line Statistics (Design 500)

DESIGN 500 LINE	VEH.TYPE	NUMBER VEH'S	ROUTE LENGTH	ROUTE TIME	HEAD-WAY	OPERATING COSTS/HR
1	40-FOOT BUS	6	62260	144	30	386
2	40-FOOT BUS	5	55880	130	30	330
3	40-FOOT BUS	3	40760	76	30	212
4	40-FOOT BUS	12	116780	298	30	757
5	40-FOOT BUS	7	70500	160	30	446
6	40-FOOT BUS	6	41980	138	30	346
7	40-FOOT BUS	3	20500	62	30	172

TABLE 6 Global Design Comparison (Designs 200, 300, 400, and 500)

DESIGN:		200	300	400	500
NO. OF LINES:	RAIL	0	0	0	0
	BUS	13	10	10	7
	TOTAL	13	10	10	7
VEHICLE REQUIREMENTS:	RAIL	0	0	0	0
	BUS	89	39	42	42
	TOTAL	89	39	42	42
TOTAL OPERATING COSTS:	($)	5700	2400	2600	2600
NO. OF VEHICLE-KM:	RAIL	0	0	0	0
	BUS	1767	717	791	818
	TOTAL	1767	717	791	818
PER CENT OF TRIPS ASSIGNED:		96.54	92.90	94.72	96.54
NO. OF PASSENGER-KM.:		9000	9600	9900	9900
AVERAGE TOTAL TRIP TIME:	(MIN)	47.6	54.8	57.7	58.0
NO. OF TRANSFERS:		200	600	600	500

TABLE 7 Overview Statistics (Design 600)

```
DESIGN                                                 600

NO.OF LINES: RAIL                                        0
             BUS                                         7
             TOTAL                                       7

ROUTE LENGTH:RAIL                                        0 (KM )
             BUS                                       301 (KM )
             TOTAL                                     301 (KM )

TOTAL TRIP DEMAND                                      549
NO. OF ASSIGNED TRIPS                                  540
NO. OF UNASSIGNED TRIPS                                  9

AVERAGE SEATING & STANDING ROOM UTILIZATION:RAIL       0.0 ( % )
                                            BUS       16.6 ( % )
                                            TOTAL     16.6 ( % )

PASS.-KM (=SUM OF TRIP LENGTHS)                       9600
PASS.-HRS (=SUM OF TRIP TIMES)                         480

AV. TOTAL TRIP TIME                                   43.9 (MIN)
AV. TOTAL WAIT TIME                                    7.8 (MIN)
AV. TOTAL TRANSFER TIME                                1.5 (MIN)
AV. TOTAL WALK TIME                                    0.4 (MIN)
AV. TOTAL TRAVEL TIME                                 53.6 (MIN)

 NO. OF TRANSFERS                                      310

VEHICLE REQUIREMENTS AND OPERATING COSTS

DESIGN      600

VEHICLE TYPE          NUMBER  VEH.KM  COST/KM  COST/H OP.COST/H

---------------------------------------------------------------
TOTAL RAIL VEHICLES      0       0                        0.
40-FOOT BUS             40     771     0.98    44.00   2516.
---------------------------------------------------------------
TOTAL BUS VEHICLES      40     771                     2516.

TOTAL VEHICLES          40     771                     2516.
```

TABLE 8 Transit Line Statistics (Design 600)

DESIGN 600

LINE	VEH.TYPE	NUMBER VEH'S	ROUTE LENGTH	ROUTE TIME	HEAD-WAY	OPERATING COSTS/HR
1	40-FOOT BUS	6	62140	140	30	386
2	40-FOOT BUS	4	53760	100	30	282
3	40-FOOT BUS	8	63740	197	30	477
4	40-FOOT BUS	6	66020	146	30	393
5	40-FOOT BUS	3	23680	70	30	178
6	40-FOOT BUS	3	17480	55	30	166
7	40-FOOT BUS	10	65640	166	20	633

DESIGN 600

LINE	VEH. TYPE	HEAD-WAY	CAPACITY SEAT	STAND	TOTAL	LOADINGS MAX	AV.	UTIL.
1	40-FOOT BUS	30	100	50	150	93	30	20.0
2	40-FOOT BUS	30	100	50	150	81	24	16.0
3	40-FOOT BUS	30	100	50	150	49	20	13.3
4	40-FOOT BUS	30	100	50	150	40	12	8.0
5	40-FOOT BUS	30	100	50	150	19	7	4.7
6	40-FOOT BUS	30	100	50	150	46	10	6.7
7	40-FOOT BUS	20	150	75	225	197	63	28.0

In design 600 the attempt was to reduce the average total travel time and the number of transfers. This design has seven routes, which are plotted in Figure 6. The base network for all the designs discussed here is the same as that of design 200 (the existing system). Table 7 gives the overview statistics. In design 600 the route length has been reduced to 301 km from 394 km in design 500. The average seating and standing use has been increased to 16.6 percent from 16.1 percent in design 500. The average total trip time has been reduced by 4.4 min and the average total wait time by 1.9 min. The number of transfers has been reduced from 490 (design 500) to 310. The reduction in transfers was achieved mainly by restructuring the routes. This was aided by examining trip desire line displays and studying the transfer movements at all transfer stops using TNOP menu item 63. The total number of buses required by this design is 40. Note that this design used a headway of 30 min, the maximum allowed. Table 8 gives the transit line statistics and it may be seen that all the lines except line 7 have a headway of 30 min. In addition, all these lines have more capacity than required by maximum loading. Table 9 gives a comparison of design 600 and the existing system (design 200). The proposed design, design 600, has six fewer routes, 49 fewer vehicles, and a savings of $2,200 per hour. The average total trip time has been increased by 6.0 min and the number of transfers by 100.

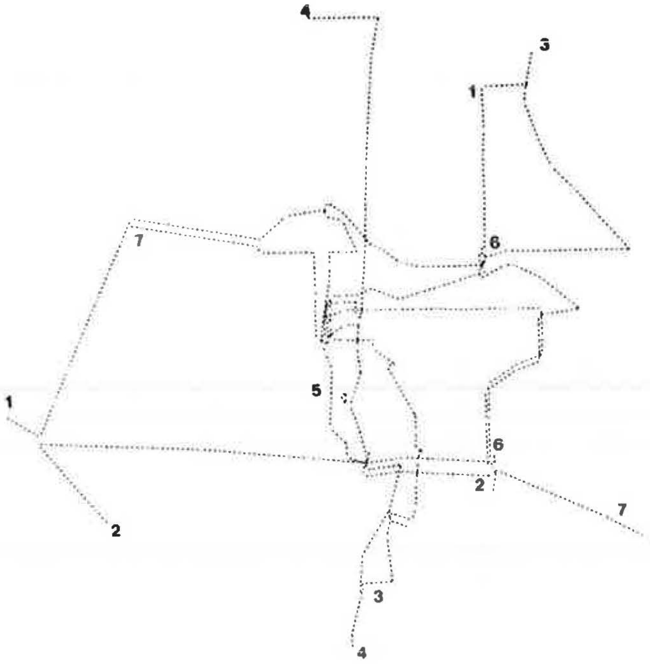


FIGURE 6 Graphic overview of bus lines (design 600).

Timetable optimization has been executed for this design. Table 10 gives the cyclic terminal departure times for all the lines. Transfer delay distribution before and after timetable optimization is shown in Figures 7 and 8. Note that transfer delay has been reduced from 4,589 to 3,306 min, a considerable reduction of 28 percent.

The energy consumed on transit routes is directly proportional to the total number of vehicle-kilo-

TABLE 9 Global Design Comparison (Designs 200, 600, 700, and 800)

DESIGN:		200	600	700	800
NO. OF LINES:	RAIL	0	0	0	0
	BUS	13	7	7	7
	TOTAL	13	7	7	7
VEHICLE REQUIREMENTS:	RAIL	0	0	0	0
	BUS	89	40	31	28
	TOTAL	89	40	31	28
TOTAL OPERATING COSTS:	($)	5700	2500	1900	1700
NO. OF VEHICLE-KM:	RAIL	0	0	0	0
	BUS	1767	771	580	523
	TOTAL	1767	771	580	523
PER CENT OF TRIPS ASSIGNED:		96.54	98.36	98.36	98.36
NO. OF PASSENGER-KM.:		9000	9600	9600	9600
AVERAGE TOTAL TRIP TIME:	(MIN)	47.6	53.6	53.6	53.6
NO. OF TRANSFERS:		200	300	300	300

TABLE 10 Cyclic Terminal Departure Times

LINE	MODE	HDWY.	TERMINAL 1			TERMINAL 2			NO.OF
				DEPART.	LAYOVER		DEPART.	LAYOVER	VEHICLES
1	B	30.0	CSEA	0.0	20.2	JC	0.0	20.2	6
2	B	30.0	BOEI	0.0	10.1	BK	0.0	10.1	4
3	B	30.0	REDM	0.0	21.4	RENT	0.0	21.4	8
4	B	30.0	BOTH	0.0	17.1	AF	0.0	17.1	6
5	B	30.0	BK	15.0	9.8	GY	0.0	9.8	3
6	B	30.0	BK	15.0	17.7	GO	0.0	17.7	3
7	B	20.0	ISSQ	0.0	17.1	UW	0.0	17.1	10

meters. The total number of vehicle-kilometers for designs 600 (proposed design) and 200 (existing system) are 771 and 1,767, respectively. Therefore, design 600 saves 996 vehicle-kilometers, a reduction of 46 percent, which would result in savings in energy. This vehicle-kilometer estimate does not take deadheading kilometers into account. It may be concluded that design 600 can save approximately 56 percent of the energy being used by the existing system.

Because design 600 used a maximum headway of 30 min, the line capacity provided in six of seven lines was more than required. An analysis has been made to determine the effect of changing the maximum policy headway to 45 and 60 min in the peak period. Designs 700 and 800 were generated on the basis of design 600. The route structure is the same as that of design 600. The transit line attributes were modified and the trips were assigned.

Maximum allowable headways of 45 min for design 700 and 60 min for design 800 were assumed. Table 10 gives global design comparisons of designs 200, 600, 700, and 800. The number of trips assigned, passenger-kilometers, average total trip time, and transfers remained at the same level on design 600. There was no change in the average total trip time among designs 600, 700, and 800, even though the headways are different. The reason was the use of logarithm of wait time in the trip assignment menu. By shifting the minimum headway from 30 to 45 and 60 min, a savings of 67 and 70 percent over the energy used by the existing system could be obtained.

CONCLUSIONS

This study was designed to investigate the potential for achieving energy savings by restructuring the routes and service of an existing system. It was also used to test the effectiveness and ability of TNOP to simulate the existing system as well as to assist in the design of more energy-efficient transit services. The study used O-D data collected by Metro's on-board survey of 13 routes in the Bellevue area. Initially TNOP was used to simulate the existing system and was able to do so satisfactorily. Based on this, more energy-efficient designs were generated for 30-, 45-, and 60-min headways. Encouraging results have been obtained by making changes in the route structure and service attributes to better match the current demand pattern. The route changes involved were simple. Overlapping routes were removed. Three routes were left unchanged. Three other routes were extended to reach more locations. One other route has the same origin and destination but uses a different path. Table 11 gives a

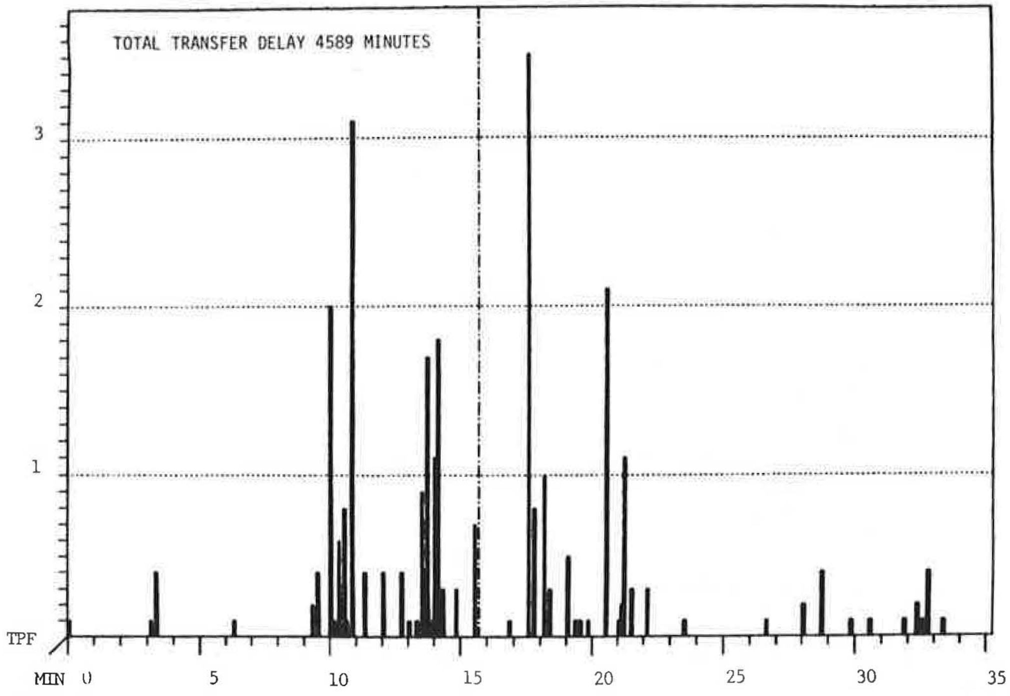


FIGURE 7 Before timetable optimization.

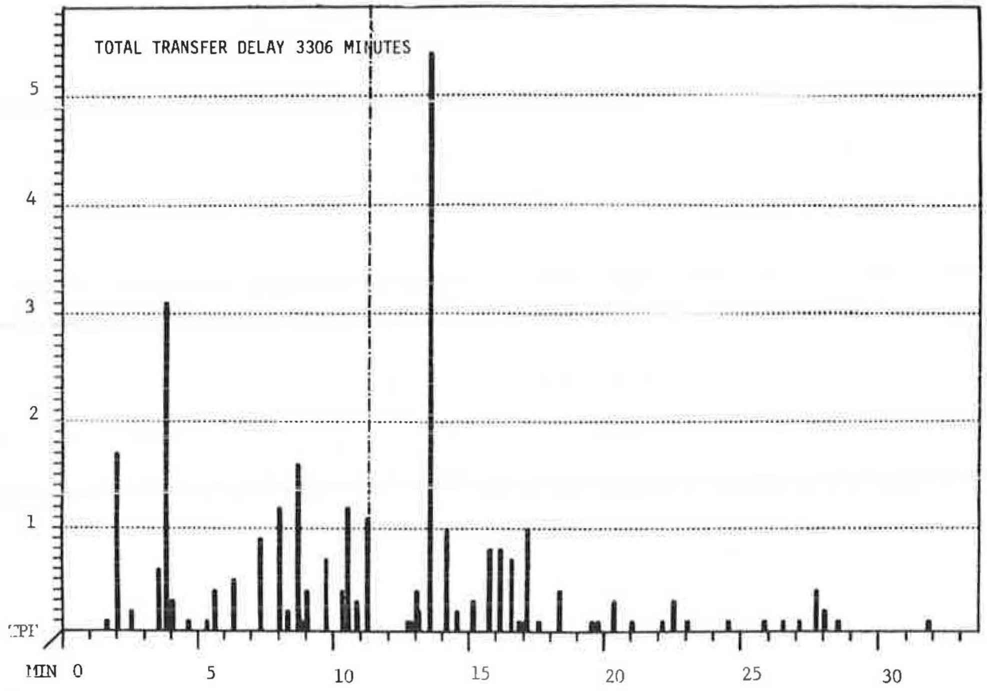


FIGURE 8 After timetable optimization.

TABLE 11 Comparison of the Performance of the Existing and Proposed Designs

Performance Measure	Existing Design	Proposed Design	% Change
A. Less Is Better			
Route length (km)	387	301	- 22.0
Number of routes	13	7	- 46.0
Passenger-kilometers	8900	9600	+ 8.0
Passenger-hours	420	480	+ 14.0
Average total trip time (min.)	40.8	43.9	+ 8.0
Average wait time (min.)	6.0	7.8	+ 30.0
Average walk time (min.)	0.5	0.4	- 20.0
Average travel time (min.)	47.6	53.6	+ 12.6
Number of transfers	160	310	+ 93.8
Transfers per passenger	0.3	0.57	+ 90.0
Number of vehicles	89	40	- 55.1
Vehicle kilometers	1767	771	- 56.4
Operating cost per hour ($)	5683	2516	- 55.7
Total transfer delay (min.)	2180	3306	+ 51.7
Average cost/vehicle kilometer ($)	3.22	3.26	+ 1.2
Average cost/passenger hour ($)	13.53	6.89	- 49.1
B. More Is Better			
Average utilization (%)	6.9	16.6	+241.0
Per cent trips assigned	96.5	98.4	+ 1.1
Trip time/travel time	0.86	0.82	- 4.7

comparison of different performance measures for the existing design (design 200) and the proposed design (design 600).

The data in Table 11 indicate that, for 16 performance measures, "less is better." The proposed design is better in 7 of these 16 categories and worse in 9. However, most of these impairments are small and of little consequence. Transfers and transfers per passenger are sharply up and this is an undesirable result. But, this impairment has to be traded off with the sharp drop in operating costs for the system. In the "more is better" category, a large increase in average use was obtained and this result, when added to the lower costs, mitigates the burden of more transfers and the somewhat longer travel times associated with the proposed design. In some situations this trade-off would be done differently and TNOP allows the planner to quickly estimate the cost of reducing the volume of transfers by increasing the cost of the service provided.

The proposed design (design 600) saves approximately 56 percent of the energy used by the existing system. The total fuel costs for the entire Metro system amounted to $7.3 million for 1982. The Bellevue area uses about 23 percent of the service provided by the entire Metro system. If the energy-efficiency study were extended to the whole of Bellevue and if a savings of 50 percent were found, approximately $900,000 could be saved every year (i.e., 11 percent of Metro's 1982 fuel bill). If similar results could be found in other suburban parts of the transit system, even more significant fuel cost savings could be obtained. Restructuring the routes and service in developed areas such as the inner city and the middle city may not yield similar levels of savings because of various constraints such as heavy automobile congestion and the difficulty of moving routes that have been in place for 40 years or longer. Nevertheless, an examination of an inner city area should be conducted to determine how much energy might be saved by a more efficient route and schedule design. From this study it may be concluded that suburban areas appear to be good locations for obtaining substantial energy savings payoffs through restructuring the routes and service level of an existing system.

ACKNOWLEDGMENTS

This project was carried out by the Department of Civil Engineering, University of Washington, Seattle, Washington, under a contract from Seattle Metro, Seattle, Washington.

This project was funded by a technical studies grant from the U.S. Department of Transportation, UMTA, under Section 6 of the Urban Mass Transportation Act of 1964, as amended.

REFERENCES

1. Bellevue--Profile of a Growing Community. Planning Department, City of Bellevue, Washington, Dec. 1980.
2. Interactive Graphic Transit Network Optimization System (TNOP): System Support Manual for GMTSC Release 1. General Motors Transportation Systems Center, Warren, Mich., Aug. 1980.
3. Interactive Graphic Transit Network Optimization System (TNOP): User's Manual for GMTSC Release 1. General Motors Transportation Systems Center, Warren, Mich., Nov. 1979.
4. N. Janarthanan and J. Schneider. Contingency Planning for Transit Services During a Gasoline Shortage Emergency Using the Transit Network Optimization Program (TNOP). Department of Civil Engineering, University of Washington, Seattle, undated.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Montgomery County, Pennsylvania, Turnpike Express Bus Study

THABET ZAKARIA, W. THOMAS WALKER, and PANAGIOTIS P. SALPEAS

ABSTRACT

A summary of the methodology, analysis, evaluation, and findings of a bus study that was conducted to assess the feasibility of park-and-ride and express bus service within the Pennsylvania Turnpike corridor is presented. Some of the fastest developing commercial and industrial areas in the Philadelphia metropolitan area are within this corridor, including many high-technology industries. A special traffic demand estimation method, which requires a special coding procedure and uses an existing traffic assignment model, was developed. This demand estimation technique reduces the computer cost of simulation, allows the use of the regional modal split and transit assignment models without recalibration, and produces accurate transit ridership estimates within the detailed study area for the routes under study. The evaluation of the promising express bus alternatives for the Pennsylvania Turnpike indicated that the subsidy for circumferential express bus routes is rather large because the patronage is generally small, even for growing and congested circumferential urban corridors.

The Pennsylvania Turnpike and US-202 Expressway describe a circumferential transportation corridor through Philadelphia's northern and western suburbs. The corridor includes a 31.4-mile segment of the turnpike between Valley Forge (Exit 24) and the Delaware Valley (Exit 29) interchanges and an 18-mile segment of US-202 Expressway from Valley Forge to the Town of West Chester, Pennsylvania. Some of the fastest developing commercial and industrial areas within the Delaware Valley region are adjacent to these two expressways. These areas include many high-technology industries, which are attracted by the access to national markets provided by the turnpike (see Figure 1) and the availability of large tracts of inexpensive land for commercial development. This growth in employment, coupled with suburban residential development, has increased traffic congestion and consequently decreased the level of

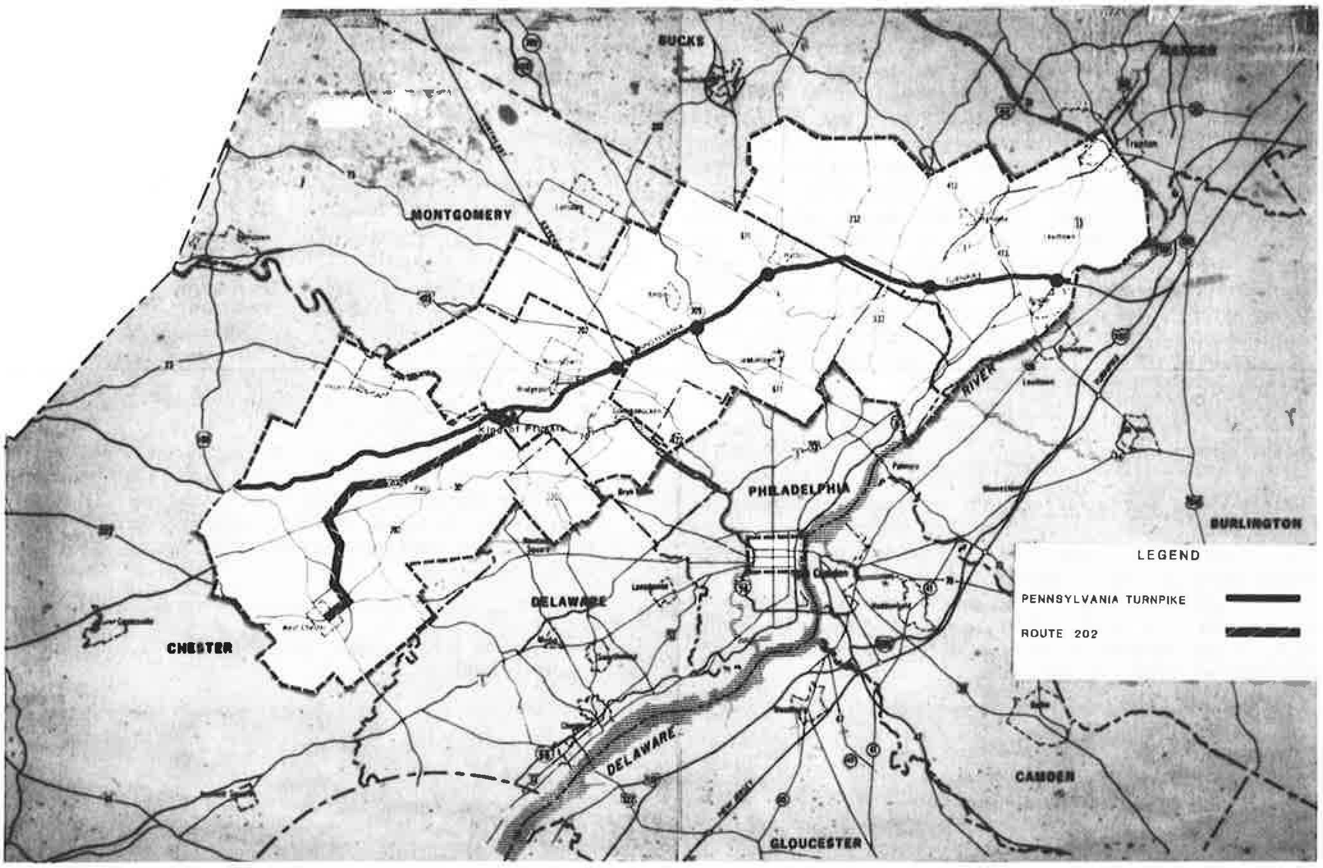


FIGURE 1 Pennsylvania Turnpike corridor planning superdistricts.

service provided by the turnpike and its surrounding road network.

A summary is presented of the methodology, analysis, evaluation, and findings of an express bus study conducted to assess the feasibility of park-and-ride and express bus service within this corridor, and to recommend an appropriate level of public transportation service. This bus service is needed to provide present and projected turnpike automobile travelers with an alternate mode of travel in order to reduce traffic congestion on the turnpike and to provide access to the employment and shopping activities within the corridor for people without access to an automobile. Guidance for the study and a review of the results were provided by a steering committee made up of representatives of Montgomery, Bucks, and Chester counties and the Southeastern Pennsylvania Transportation Authority (SEPTA), the Pennsylvania Turnpike Commission, and the Delaware Valley Regional Planning Commission (DVRPC).

CORRIDOR DEFINITION AND DATA REQUIREMENTS

In planning for new bus services, it is necessary to make an initial delineation of the area to be served by the proposed bus routes. A natural corridor is formed by an area 5 miles on either side of US-202 Expressway and the Pennsylvania Turnpike. This corridor is shown in Figure 1. The 5-mile bandwidth was chosen because previous studies had shown that the maximum trip length to park-and-ride lots would be less than 5 miles (1).

Four categories of data are required for developing and analyzing express bus service alternatives in the corridor:

1. Land uses,
2. Demographics and employment,
3. Travel characteristics, and
4. Existing transportation facilities.

Travel impact analysis requires that the data be collected for small districts (census tracts). It is also convenient to aggregate these small districts to larger superdistricts so that the amount of information can be reduced to a more manageable level. For this reason the 256 census tracts within the study area were aggregated to the four superdistricts shown in Figure 1.

Land Uses

Public transit service requires high concentrations of land-use activities in order to generate travel volumes of sufficient magnitude to make the transit routes economically viable. This land-use survey suggests the magnitude of bus services that can be supported and the location of high-density developments that may be served.

The Pennsylvania Turnpike corridor is intensively developed, particularly in the vicinity of the turnpike interchanges. All types of development--high and low density, residential, commercial, cultural, educational, medical, and industrial--are found within the corridor.

Demographic and Employment Data

Although the land-use survey is useful for locating areas of high development, more specific information about the nature of these developments is needed before precise estimates of patronage on the new bus routes can be made. Thus, estimates of demographic and employment data for small zones (census tracts for this study) must be provided. These variables include population; number of households; automobile ownership rates; and retail, commercial, industrial, and total employment.

The most recent detailed estimates for the demographic and employment variables (until 1980 Census information becomes available) were prepared for 1977 by DVRPC staff as part of the year 2000 planning process (3). These data were used for this study.

In summary, more than 1.1 million persons (22.1 percent of the regional population) live within the study corridor. Similarly, 21.1 percent of the region's households, 22.3 percent of employed residents, 25.8 percent of automobiles owned (and only 7.5 percent of households without automobiles) are located in the Pennsylvania Turnpike study area. This is a significant portion of the regional population; moreover, households within the corridor are characterized by greater than average automobile ownership, which provides them with greater automobile access for their daily travel needs.

A total of 436,322 jobs is located in the corridor. Manufacturing employment accounts for 23.3 percent of the total employment in the study area, retail 20.4 percent, and service 19.2 percent. This large concentration of employment tends to create severe traffic congestion during peak periods, particularly in the vicinity of major interchanges between freeways and arterials. Projections indicate that this corridor will grow at a high rate in population and employment (3).

Travel Patterns

Existing travel patterns for the turnpike corridor were summarized from the 1977 simulated trip tables produced as part of the year 2000 planning process. These trip tables are based on the 1977 population and employment estimates (2).

Most person-trips associated with the corridor begin and end in the corridor. Work travel is somewhat less concentrated: about 50 percent of corridor work-trip origins have their trip destinations within the corridor. About one trip in five is work related; 80 percent of travel is for shopping, personal business, and other nonwork purposes.

Overall, just over 2.4 percent of daily person-trips originating within the corridor use public transit. More than one-third of these transit trips are destined for the Philadelphia central business district, which has the highest percentage of trips made by transit of any destination of corridor travel. Only 1 percent of the person-trips that have both origin and destination within the corridor use public transit service. There are about 2 million daily automobile trips within the corridor; some of them may be diverted to public transit if a good level of transit service is provided.

Existing Transportation Facilities

The turnpike corridor originally developed as a series of commuter rail corridors radially oriented toward Philadelphia and, to a lesser extent, around Norristown. This radial orientation resulted in highway and public transit networks that are also focused on Philadelphia. Few transportation facilities are provided for cross-corridor movements, except for the turnpike--a facility constructed primarily for long-distance interstate travel.

Commuter Rail Facilities

Nine commuter rail lines cross the turnpike corridor and can be used for turnpike bus alternatives in two ways: rail stations near the turnpike interchanges can provide parking for park-and-ride bus operations, and the rail system can provide connecting transit service for riders whose trips are, in part, radial. Reduced fare transfers between bus and rail facilities are available at many suburban stations.

Bus Facilities

Only one interchange totally lacks peak-hour bus service. All other interchanges are served by at least two peak-hour bus routes. Like the commuter rail lines in the corridor, these bus routes provide primarily radial service oriented to Philadelphia. At present, there is no bus route that provides service on or parallel to the turnpike.

Highway Facilities

The turnpike corridor contains many miles of freeways and high- and low-type arterial roads. However, poor provision is made for east-west vehicular movement across Montgomery County. The only major east-west road in the central portion of the turnpike corridor is the turnpike itself.

Turnpike traffic within the study area has been stable since 1977. The greatest link volume--48,000 vehicles per day--occurs between the Norristown interchange and the Northeast Extension junction. A large portion of turnpike travel has both its origin and its destination within the corridor. The maximum toll for turnpike travel within the corridor is $1.15 (for travel from the Valley Forge interchange to the Delaware River Bridge interchange). The minimum toll charge is $0.30 for one interchange movement.

Parking Facilities

All turnpike interchanges have park-and-ride lots available near the interchange. Shopping centers, industrial parks, and rail stations afford excellent parking facilities for park-and-ride operations.

DEVELOPMENT OF BUS ROUTE ALTERNATIVES

Three items were considered in the development of viable alternative bus routes for the corridor. These include potential locations for park-and-ride lots and routing for distribution loops; bus route configuration and service characteristics; and operating characteristics including headways, travel times, fares, and operating costs.

Potential Bus Service Areas

The land-use inventory identified high-density concentrations of commercial and residential development in the vicinity of the turnpike and US-202 Expressway interchanges that may be served by an express bus. In defining the park-and-ride lot and passenger distribution loops in these areas, provision for transfer to existing radial transit routes was made wherever possible.

Express Bus Service Patterns

Five types of express bus service operation were considered. They were line-haul on the turnpike and US-202 Expressway with buses routed through each distribution loop in series, line-haul with transfer to a distribution loop shuttle bus at each freeway interchange, line-haul with transfer to existing transit routes at the freeway interchanges, and binary service (direct service between the parking lot and distribution loop with the route terminating on completion of the distribution loop). Two variations of binary service were considered: independent service with each route scheduled separately, and transfer service with arrivals and departures at and from the parking lots timed to allow trips not directly served with binary service to be made through convenient transfers.

The operating characteristics of each of these modes of operation were evaluated in terms of area coverage, directness of travel, transfers, convenience and delay, service quality, network clarity and image, and operating cost and complexity.

Generally, line-haul services have good area coverage but lack service quality or efficiency and ease of operation, or both. Binary service patterns generally offer high-quality service but lack area coverage unless many routes are operated at a high operating cost.

These operating characteristics were reviewed by the policy steering committee. The line-haul service patterns were rejected because they did not offer sufficient quality to be acceptable to travelers within the corridor. Line-haul bus and shuttle service was also rejected because of excessive operational complexity and cost. All possible binary service patterns were to be considered further and evaluated so that promising routes could be identified for possible implementation.

Binary Service Bus Route Operating Characteristics

In this bus service, the express bus is accessible to all available travel modes at the park-and-ride lot. Bus patrons can park their cars and ride the bus, or they can transfer from other modes such as rail and bus. People who live within walking distance may walk to the express bus.

At the destination, however, the express bus should become a distribution vehicle or local bus that takes the passengers to their destinations. Thus, there is no need for transferring passengers to another travel mode at the destination. About 20 min would be the time required to take passengers to their destinations at each of the turnpike interchanges, except for the King of Prussia area where the bus distribution time is estimated to be 30 min.

The express bus should be operated at headways of 20 min in the peak hours and 60 min in the off-peak. With regard to the regional fare structure, SEPTA proposed a $0.75 base fare with $0.30 zone charges. Zones are usually 5.5 miles long.

TRAVEL DEMAND ESTIMATION

The binary express bus route structure defined previously resulted in 110 potential bus routes. This large number of express bus routes required a special adaptation of the DVRPC regional travel forecasting process because 110 simulation runs with the traditional simulation procedures would have resulted in excessive computer costs.

Focused Express Bus Simulation Process

The travel forecasting process used to estimate the ridership on potential turnpike express buses is shown in Figure 2. The focused simulation has several characteristics that make it desirable for use in this study (4).

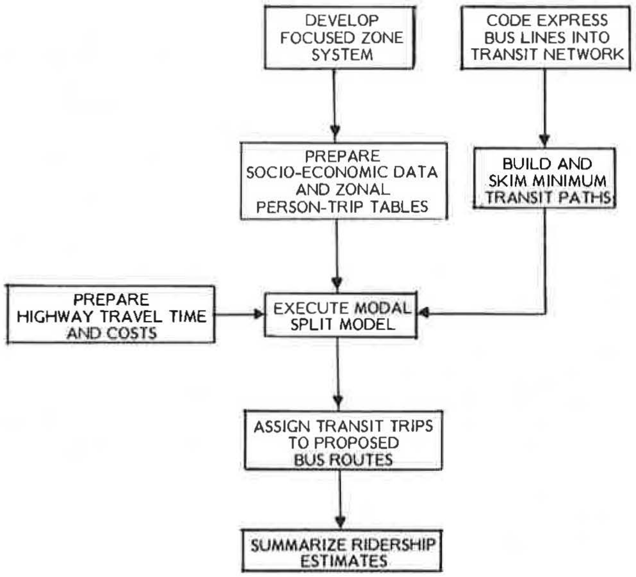


FIGURE 2 Focused express bus simulation process.

Coding the Public Transit Network

The preparation of the turnpike study network required three steps:

1. Focus the network by reducing network detail outside of the study area,
2. Update the network to include all regularly scheduled existing transit service within the corridor, and
3. Code the alternative binary turnpike bus services into the network.

At the place of origin, express bus access links were coded for all approach methods including park and ride, kiss and ride, and bus and rail. Walk approach was also coded from all centroids within 0.5 mile of the park-and-ride lot. All zones within a 3-mile radius of the park-and-ride lot in each service area were connected to the park-and-ride lot via automobile approach. An average speed of 14 mph was used to calculate the travel time needed to traverse the over-the-road distance between the zone of origin and the park-and-ride lot. An automobile operating cost of $0.22 per mile was assumed.

At the destination, a distribution loop was constructed to give potential riders direct access to their destinations. This loop was coded as follows:

1. A distribution loop time of 20 min was assumed for all service areas except Valley Forge, which was allocated 30 min for this loop;
2. This travel time was converted to a travel distance by assuming an average bus speed of 12 mph;
3. The location of employment centers within

each service area was determined and a bus loop was constructed to service these employers within the maximum travel times and distances given previously;

4. Walk approach links were coded to give direct connections between the bus distribution loop and the zones containing employment; and
5. Service headways and the fare structure noted previously were coded into the network.

As mentioned before, a special network coding procedure was devised that allowed the estimation of the patronage resulting from all 110 bus alternatives in a single run of the network generation, modal split, and transit assignment submodels. This specialized express bus coding procedure took advantage of the requirement that each express bus alternative stops only at the park-and-ride lot to pick up passengers and as necessary on the distribution loop to discharge passengers. No intermediate stops are made at service areas between the origin and destination service area. This special characteristic of the route allows the network coding to be broken into three distinct subelements (see Figure 3)--a trunk segment connecting all service areas (20-min headway service) and two satellite approach segments that connect the trunk with the park-and-ride lots and satellite distribution loops.

Because no waiting time or fare was assessed for a transfer between the satellite and the trunk segments, the total travel time and fare between origin and destination through this composite route is exactly what would be expressed by a home-to-work or home-to-nonwork trip using a direct express bus service between the park-and-ride lot and the distribution loop. The projected one-way travel volume on each proposed bus alternative is the appropriate cell in the internode volume matrix on the trunkline. This volume should be doubled to produce an estimate of total daily bus route ridership making that movement in both directions.

Modal Split Model

The modal split model operates on each person-trip interchange in the trip table (5). The model calculates a percentage of each interchange to be allocated to transit, with the residual being highway trips. In general, the better the transit service (as measured by time and cost) relative to highway travel, the higher the percentage allocated to transit. Trip purpose, transit submode, and automobile ownership are also considered in defining this relationship. The ridership loss that would be caused by combining binary routes with timed transfer or through intermediate distribution loop routing can be easily calculated by a pivot point process based on modal split model elasticities (6,7).

The DVRPC model assigns public transportation trips to the facilities that provide the best service (measured by time and cost) from the origin to the destination of the trip. During the assignment process, a transit submode (bus or rail) is selected and transit trips are "unlinked" into the assigned boardings.

Estimated Turnpike Bus Patronage

Table 1 gives the estimated ridership for each of the 110 potential bus routes evaluated as part of this analysis. Each entry in this matrix represents the average weekday ridership that would use a bus operated in a binary fashion. This ridership was taken from the intermode volume matrix of the trunkline.

An inspection of bus route patronage shows that 63 of the 110 proposed routes generate extremely low ridership (fewer than 10 trips). Of the 47 remaining buses, 31 have insignificant estimated bus ridership ranging from 11 to 30 daily trips.

The ridership estimates produced by this fore-

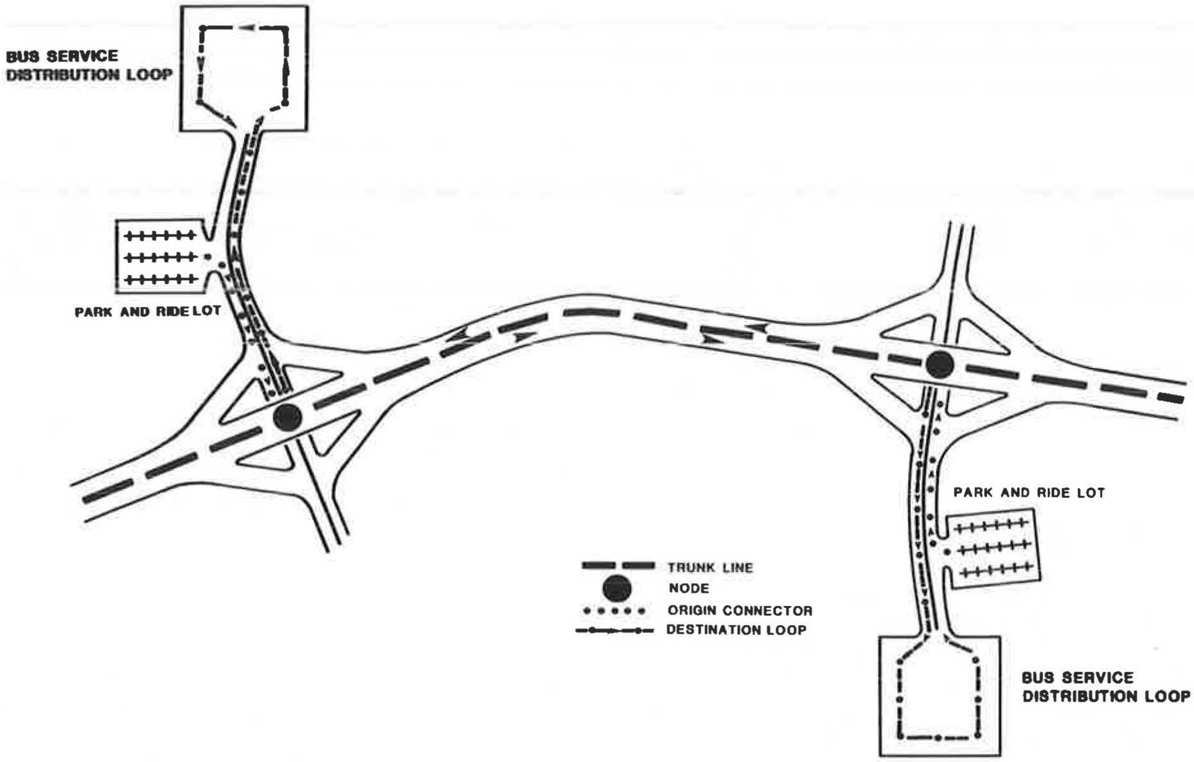


FIGURE 3 Binary coding of potential express bus routes.

TABLE 1 Estimated Daily Bus Ridership

Origin (Parking Area)	Destination (Distribution Loop)										
	Oxford Valley Mall (1)	Levittown Railroad Station (2)	Neshaminy Mall Interchange (3)	Willow Grove Interchange (4)	Fort Washington Interchange (5)	Norristown Interchange (6)	Valley Forge Interchange (7)	Valley Forge Music Fair Area (8)	Paoli Railroad Station (9)	Exton Mall (10)	W. Chester Railroad Station (11)
Oxford Valley Mall (1)		*	16	*	*	16	*	*	*	*	*
Levittown Railroad Station (2)	*		*	12	*	12	*	*	*	*	*
Neshaminy Mall (3)	30	*		16	14	26	*	*	*	*	*
Willow Grove Interchange (Exit 27) (4)	*	16	20		68	80	*	*	14	*	20
Fort Washington Interchange (Exit 26) (5)	12	*	12	30		140	20	*	16	*	32
Norristown Interchange (Exit 25) (6)	16	*	*	24	120		34	14	22	*	20
Valley Forge (Exit 24) (7)	30	*	*	*	*	*		*	14	*	44
Valley Forge Music Fair Area (8)	*	*	*	*	*	18	24		*	*	18
Paoli Railroad Station (9)	28	*	*	*	38	42	46	*		*	38
Exton Mall (10)	*	*	*	*	*	12	48	*	*		*
W. Chester Railroad Station (11)	*	*	*	*	20	38	278	16	98	*	

Note: Each entry of this matrix represents the sum of passenger trips from the Park and Ride lot to the destination and the return trip. The ridership in this table is representative of the average weekday volumes that would occur on direct express bus service between the Park and Ride lot and the distribution loop via US-202 and/or the Pennsylvania Tkp.

*Less than 10 trips

casting method seem to be reasonable on the basis of three available data items: (a) an employment survey identifying the place of work for Bucks County residents and their mode of travel, (b) traffic counts and patterns on the turnpike, and (c) the percentage of transit trips for work trips by the U.S. Census Bureau and DVRPC regional simulation. A comparison of the estimated patronage with these data indicated that the error of forecasting is small, and the results are acceptable for all planning purposes. The 1977 calibration results for focused transit assignment indicated that the percent RMS error is about 15 percent for station and park-and-ride volumes (8).

Peak and Off-Peak Distribution of Bus Ridership

To determine the peak and off-peak distribution of turnpike express bus ridership, current ridership counts by hour were examined for existing suburban circumferential bus routes. On the average, about 46 percent of the daily rides on these routes occur during peak hours and 54 percent during the midday. On this basis, it was expected that about one-half of the turnpike bus ridership would occur during peak periods.

EVALATUION OF EXPRESS BUS ROUTES

The evaluation of alternative express bus services should consider both the direct and indirect costs and the benefits associated with this type of bus service. These benefits and costs can be grouped into three general categories--those accruing to transit operators, users, and nonusers.

Transit Operator Costs and Revenues

The evaluation criteria considered by the transit operator are principally financial. That is, the operating ratio (revenue to cost) should be commensurate with the subsidy policies applied to other existing bus lines.

Bus Operating Costs

For the purpose of calculating operating costs, representative schedules were developed for each of the four most promising bus routes shown in Figure 4.

The daily operating costs for these routes vary from $1,211 per weekday for the West Chester-Valley Forge service to $533 per weekday for the Willow

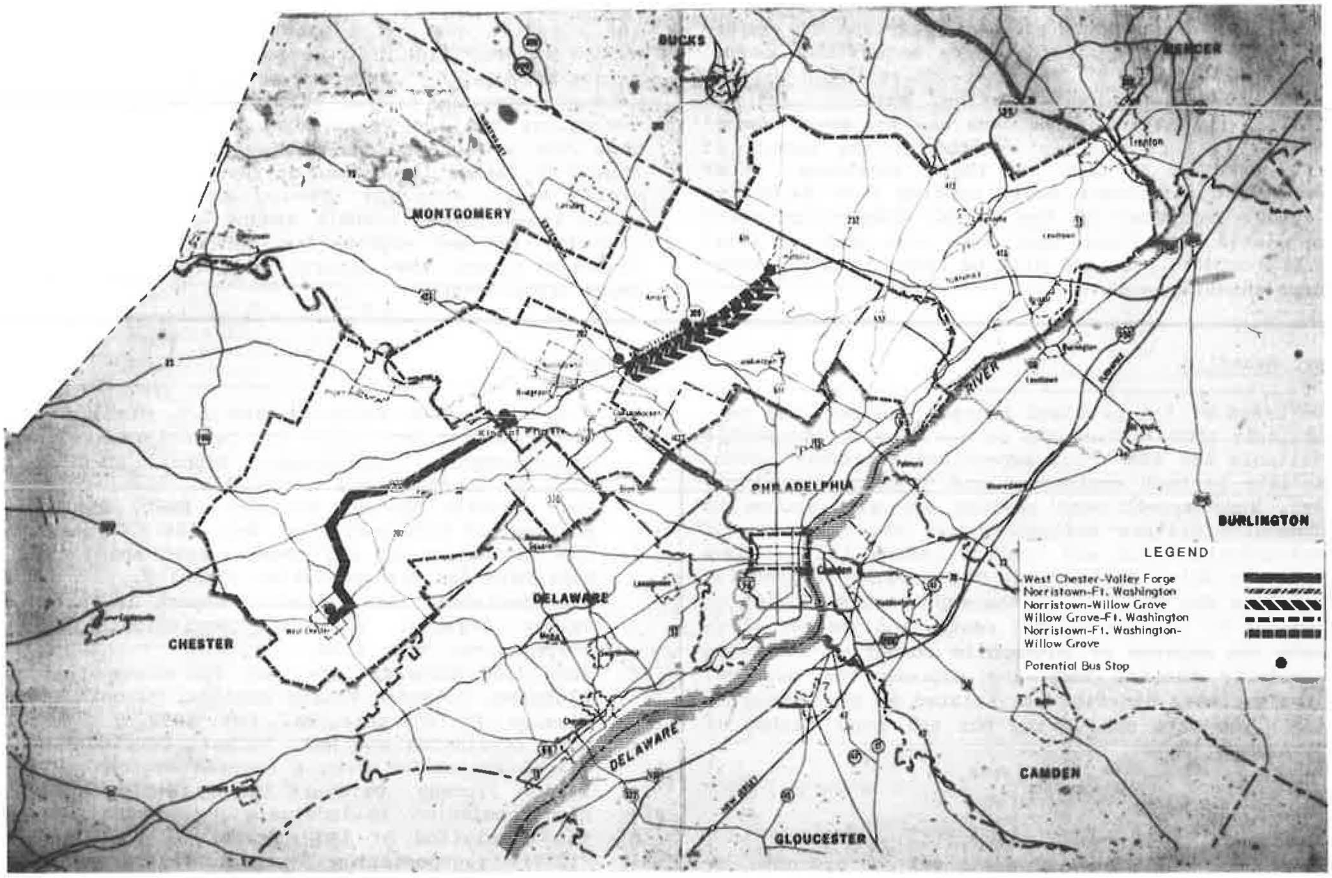


FIGURE 4 Pennsylvania Turnpike corridor potential express bus routes.

Grove-Fort Washington service. The major factor accounting for this difference is route length.

The West Chester-Valley Forge service generates the most revenue ($440 per weekday) reflecting the route length and sizable patronage; and the Willow Grove-Fort Washington service shows the least revenue ($75 per weekday).

The annualized revenue, operating cost, and operating ratio for each promising bus route are given in Table 2. The most promising route in terms of projected operating ratio is the West Chester-Valley Forge service, with a 0.36 operating ratio. Reflecting the relatively high potential ridership generated by this route, the West Chester-Valley Forge service also requires the largest annual subsidy.

The proposed West Chester-Valley Forge and composite Norristown-Fort Washington-Willow Grove routes both have operating ratios greater than 0.3, the minimum level used by SEPTA to consider operating a suburban bus route.

TABLE 2 Operating Ratios for Promising Turnpike Corridor Bus Routes

Route	Annual Fare Box Revenue ($)	Annual Operating Cost ($)	Annual Subsidy ($)	Operating Ratio
West Chester-Valley Forge	114,400	314,860	200,760	0.36
Norristown-Fort Washington	50,700	218,920	168,220	0.23
Norristown-Willow Grove	28,600	161,200	132,600	0.18
Willow Grove-Fort Washington	19,500	138,580	119,080	0.14
Norristown-Fort Washington-Willow Grove	84,500	272,480	187,980	0.31

Note: An annualization factor of 260 was used to convert average weekday estimates to annual estimates. The operating cost was estimated using a unit cost of $1.05 per bus-mile and $9.91 per bus-hour.

Capital Costs and Other Operating Costs

The promising turnpike bus routes have other costs besides the cost of operating the proposed bus service. These costs fall into two categories: the cost of acquiring the buses needed for the proposed service and the cost of implementing and maintaining the park-and-ride lots associated with these services. Table 3 gives the capital cost required to provide the buses for the four most promising express bus alternatives. It should be noted that the existing SEPTA bus fleet may be used to operate all or part of these proposed bus routes by using surplus buses or shifting surplus service from existing routes.

TABLE 3 Vehicle Capital Costs for Promising Turnpike Bus Routes

Route	Vehicle Requirements	Total Capital Cost (1982 dollars)
West Chester-Valley Forge	5	800,000
Norristown-Fort Washington	4	640,000
Norristown-Willow Grove	3	480,000
Willow Grove-Fort Washington	3	480,000
Norristown-Fort Washington-Willow Grove	5	800,000

Note: These vehicle requirements may be substantially reduced by using existing surplus buses in the SEPTA fleet or by shifting surplus service from existing routes.

Capital and operating costs for each of the park-and-ride lots served by promising express bus alternatives, excluding parking space acquisition costs, were also calculated. The park-and-ride lot capital cost includes signing, lighting, marking, and bus shelters needed to accommodate the projected number of riders. This cost is related to the number of cars expected to park at these locations. These costs were relatively small ranging from $4,000 to $17,000. Estimates of the annual maintenance costs associated with these lots were also made. A total of approximately $9,900 will be spent in lot maintenance annually.

User Benefits

The users of the proposed express bus service, particularly those riders who do not have an automobile available for the trip, experience increased accessibility to both employment and shopping opportunities. Some travel cost savings may also accrue to automobile drivers and passengers who make use of park-and-ride lots and thereby reduce the distance that they drive their cars. Those former automobile travelers who can walk to the express bus service or transfer to it from another route, and thereby eliminate the expense of automobile commuting entirely, especially benefit from the express bus service. Clearly, these benefits are related to the number of riders who make use of the bus and their method of approaching it.

Nonuser Benefits

The benefits of the express bus service are not limited to the riders of this service. Clearly, nonusers of the service also benefit. These benefits to society take the form of reductions in air pollutant emissions, energy savings, and reduced highway congestion. In general, these bus routes will not have significant impact on traffic congestion, pollution emission, or gasoline consumption. All reductions in these indicators are less than 1 percent of existing levels.

It is clear from this evaluation that the most promising bus routes for implementation are West Chester-Valley Forge express bus via US-202 Expressway and Norristown-Fort Washington-Willow Grove bus via the turnpike.

Before implementation, however, these routes should be further studied as part of the ongoing detailed transit studies concerning the operation and integration of these routes with the existing transit system, which has been changed slightly since the completion of this study.

CONCLUSIONS

A special traffic demand estimation method, which requires a special coding procedure and uses the existing regional travel demand model, was developed. The travel demand forecasting method reduces the computer cost of simulation and produces accurate transit ridership estimates for the transit routes selected for study and evaluation.

The evaluation of the promising express bus alternatives for the Pennsylvania Turnpike indicated that the subsidy for circumferential express bus routes is rather large because the patronage is generally small, even for growing and congested suburban areas. Heavy transit demand that justifies a park-and-ride and express bus service is generally oriented toward the central business district in large urban areas.

REFERENCES

1. J.W. Flora, W.A. Stimpson, and J.R. Wroble. Corridor Parking Facilities for Carpoolers, Vol. 2: Implementation Guidelines. Report RD-80-169. Alan M. Voorhees and Associates, Inc., McLean, Va.; Traffic Systems Division, FHWA, U.S. Department of Transportation, Feb. 1981.
2. The Estimation of 1977 Demographic and Employment Data for Transportation Planning. Year 2000 Transportation Plan Technical Report 2. Delaware Valley Regional Planning Commission, Philadelphia, Pa., Nov. 1976.
3. Year 2000 Forecast Data Bank for Transportation Planning. Delaware Valley Regional Planning Commission, Philadelphia, Pa., Oct. 1979.
4. C.G. Herrington and W.T. Walker. Corridor-Level Travel Estimation with a Focused Regional Simulation Process. Delaware Valley Regional Planning Commission, Philadelphia, Pa., March 1980.
5. The Simulation of 1977 Travel on the Current (1977) Transportation Systems. Delaware Valley Regional Planning Commission, Philadelphia, Pa., June 1977.
6. Guidelines for Travel Demand Analysis of Program Measures to Promote Carpools, Vanpools, and Public Transportation. Cambridge Systematics, Inc., Cambridge, Mass., Nov. 1976.
7. Modal Split and Auto Occupancy Sensitivity Analysis. Delaware Valley Regional Planning Commission, Philadelphia, Pa., June 1982.
8. The Testing of Travel Forecasting Models. Report prepared for the PATCO Berlin/Atco Extension Study. Delaware Valley Regional Planning Commission, Philadelphia, Pa., Oct. 1981.

This paper was financed in part by UMTA, U.S. Department of Transportation, by the counties of Montgomery, Bucks, and Chester, Pennsylvania, and by the Southeastern Pennsylvania Transportation Authority. The authors, however, are responsible for the findings and conclusions that may not represent the official views or policies of the funding agencies.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Systems Approach to Transit Bus Maintenance

MAXIMILIAN M. ETSCHMAIER and GEORGE ANAGNOSTOPOULOS

ABSTRACT

A review of transit bus maintenance shows that, as widely suspected, there are serious problems. Solutions to parts of the problem have not succeeded in improving the overall situation. Instead, a total system approach is advocated. Elements of such an approach are outlined.

A number of recent studies have pointed out that significant problems exist in maintenance of transit buses. Figure 1, reproduced from Malec (1), shows that between 1973 and 1982 maintenance costs for buses in transit service increased fivefold, from around $0.20 per mile to close to $1.00, an average annual rate of increase of 20 percent. At the same time, the miles that a bus operated between road calls decreased from more than 5,000 to a mere 2,000. Although the decrease in miles between road calls may have leveled off recently, indications are that the cost increase continues.

The Committee on Public Works and Transportation of the U.S. House of Representatives, as quoted in a report by the General Accounting Office (2), finds a tendency among transit companies to defer maintenance work in order to defer cost. Because the consequences of deferred or not-performed maintenance often are not evident until much later, the report states that "the chickens usually come home to roost at some later date, when a new cast of characters may be in place."

The report by the General Accounting Office cites numerous specific incidents of transit companies not following their own maintenance programs, performing inspections called for in these programs either late or not at all. In contrast with this situation is a public sentiment of increasing impatience with inefficiency or ineffectiveness of any form of public service. The public refuses to go along with ever-increasing fares and demands a reduction in the subsidy payments for transit. Transit companies thus find themselves in a squeeze: continuously increasing cost versus resources that are steady at best and declining in some instances. Clearly some change is necessary.

The General Accounting Office report recommends a federal policy for transit bus maintenance. They recognize that there are significant differences among transit companies throughout the country. The policy they call for, therefore, is to be flexible and to leave room for the individuality of each transit company. This conclusion points in the same direction as the work that has been going on for more than 2 years under the sponsorship of the Planning and Methods Division of UMTA at the Transportation Systems Center.

The work at the Transportation Systems Center has led to the formulation of a dynamic approach to management of maintenance (3). The central idea of this

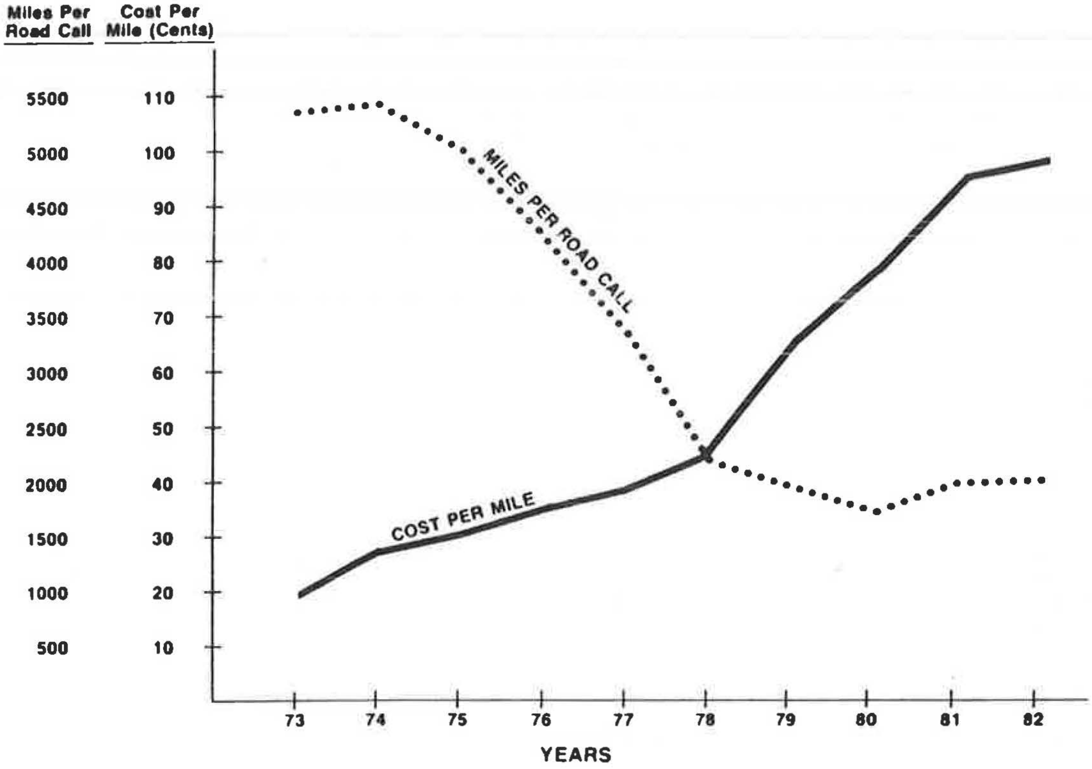


FIGURE 1 Cost and performance of transit bus maintenance, taken from Malec (1).

approach is that the deterioration of operating equipment is by its very nature random. Maintenance, if it is to be efficient, therefore has to be structured in a flexible manner so that it can respond to any randomly arising need for work. The best design of a maintenance system is based on an intimate understanding of the design and operating environment of the equipment. Also, it takes into account the resources available and applies these resources to most effectively meet the maintenance needs. The best understanding of resources and equipment resides within each transit company itself. A dynamic maintenance system will therefore have to evolve from within each transit company. The methodology formulated at the Transportation Systems Center is intended to support this evolution.

Efforts at improving the situation in transit maintenance have been under way for a long time. Much good work has been done, but most of it has been focused on isolated parts of the entire problem. To the extent that a systems concept behind these efforts can be identified, that concept appears to be improvement of the hardware design of a bus and its components, or automation of maintenance to reduce the reliance on humans in the performance of maintenance.

The purpose of improving the hardware is to reduce the frequency of failures and the amount of maintenance work required. The introduction of air starters and the tests of alternate brake linings are examples of these efforts. At the bus level, the introduction of life-cycle costing is motivated by the desire to force consideration of maintenance expenses into the procurement process.

Automating maintenance is an attempt to get around the sometimes difficult labor situation. Some transit companies appear to be limited in the qualification standards they can demand of mechanics, others have to deal with highly restrictive work rules. The Automatic Bus Diagnostic System tested in New York City (4) is an example of such an effort.

Both types of efforts may have led to improvements in the areas they were directed at. However, implementation of solutions often proved expensive. Above all, as the figures quoted previously show, no significant improvement either in cost or in performance has materialized. The conclusion of the work at the Transportation Systems Center is that significant improvements in overall performance can be expected only if these efforts are part of an overall systems approach.

The dynamic approach to maintenance is the result of efforts to provide a guide for the use of the systems approach in transit bus maintenance. In the following sections a brief overview of the most important features of this approach will be given, and some of the potential for improvement of the situation that might be expected to result from its implementation in transit bus maintenance will be pointed out.

A SYSTEM VIEW OF MAINTENANCE

The role of maintenance in a transit company is to provide the vehicles required for the performance of the planned operations at the time when these vehicles are needed and to assure that the vehicles are, and will continue to be throughout the duration of their assigned mission, in safe operating condition. Maintenance, thus, has no purpose in itself; it exists only as a support function. However, the service that a transit system can offer is determined by the characteristics and capabilities of maintenance, as it is by the characteristics and capabilities of other parts of the system. A view of a typical transit system is shown in Figure 2. The three major functional elements, marketing, operations, and maintenance, are all interdependent and share coequally in the responsibility for the support of the entire system.

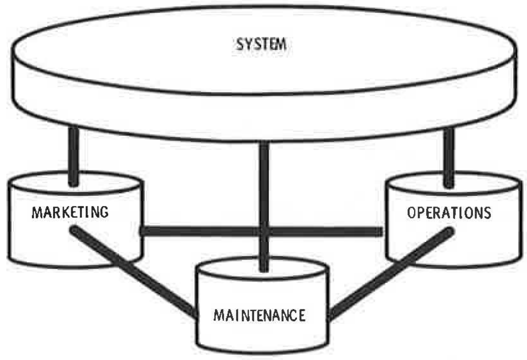


FIGURE 2 Typical transit system.

One review of transit maintenance (5) shows that, contrary to this view, maintenance is frequently isolated from the rest of the company. Top management often does not understand maintenance and "too often . . . [maintenance] is viewed as an operating function which mysteriously works by itself" (6). Although there are increasing numbers of attempts to hold maintenance accountable and to measure its performance through management information systems, there is little evidence of attempts to understand the role and special needs of maintenance. Maintenance personnel typically are not listened to but talked down to. Their jobs are considered dead ends on a career path and few of them ever make it into top management ranks. If they do, it is often by moving to another career path. The situation of maintenance in transit is by no means unique. It appears that, with the exception of some industries with very high technology and with obvious safety implications of bad maintenance, a lack of understanding of maintenance is commonplace. Characteristically, the word maintenance is frequently used as a euphemism for janitorial service.

A systems analysis of maintenance has to be preceded by an analysis of the entire transit system and the definition of a consistent set of objectives. This will lead to a definition of objectives, role, and mission of maintenance within the total system. Critical in this definition is the identification of interests that overlap those of other functional areas.

Examples of interests that overlap those of the operations function include the following areas:

- Assembly of bus runs. Maintenance is interested in the starting and finishing times of each run, as well as the slack times within runs. Run starting and finishing times determine the work-load profile for maintenance. Duration and geographic location, relative to maintenance facilities, of slack times determine whether or not problems encountered during the day can be corrected without disruption of service.
- The total number of buses in service during the course of the day and the number and positioning of standby buses and drivers within the system.
- Definition of response strategies to in-service difficulties.
- Design of communications and other interfaces

between bus operators, dispatchers, and maintenance. Examples of this are debriefing of drivers, bus starting and servicing, and assignment of individual buses to runs.

Examples of overlapping concern with marketing are the appearance of the buses as well as the design, selection, and mode of operation of systems for passenger convenience and comfort such as seats and air conditioning.

After all areas of overlapping concern with all parts of the property have been delineated and responsibilities for them resolved, it is possible to arrive at an overall statement of responsibilities for the maintenance function. (It should be understood that the process described here in a linear fashion in reality is an interactive one, requiring many iterations before all conflicts are resolved.) A definition of responsibilities for the maintenance function includes the following areas:

- Evaluation and participation in selection of new equipment (buses, bus configurations, tools and support equipment, and so forth).
- Selection, training, and promotion of personnel.
- Maintenance of an inventory of spare parts.
- Definition of components and subsystems that are to be treated as repairables. For each of these components, determination of optimal float levels and control of the cycle (i.e., assurance of an adequate level of components in serviceable condition).
- Evaluation of proposed future bus operations schedules.

DETERMINISTIC VERSUS DYNAMIC APPROACHES TO MAINTENANCE

A review of maintenance practices in transit companies shows a strong tendency to make maintenance predictable, deterministic. If a manager of maintenance could plan work a long time into the future, there would be no surprises and no crises. The task of maintenance management would become much easier and much of the well-developed methodology of production management could readily be applied.

Unfortunately, maintenance is by its very nature random and any effort to make it deterministic is bound to be expensive. The alternative to the deterministic approach is a maintenance system that is capable of dynamically responding to ever-changing situations. In this section these two approaches will be contrasted.

As far as component repair, replacement, and reconditioning are concerned, the deterministic approach strives to have all work performed at predetermined times. Components are thus removed on the basis of time or accumulated operating time or mileage. The amount of work to be done on a component after removal is fixed and known in advance. A constant shop load is achieved by controlling the input into the shop. Initially, this may require removing some components earlier than necessary. But when a uniform distribution of the age of active components has once been established, a smooth shop load is assured without further planning or corrective measures. The process may be viewed as an open-loop control system.

In contrast, the dynamic approach whenever possible only calls for work to be done in response to actual needs (i.e., when the condition of the equipment requires it). Instead of completely reconditioning a component after each removal, only the work that is necessary is performed. The resulting random work load is controlled by assuring a mix of work loads with various degrees of urgency in each shop. A properly sized and managed float of spare components will accomplish this. Also, for the most expensive and significant components the occurrence of a removal may be forecast in the short run. This is the case when the condition of the component indicates that it will soon deteriorate to a state in which the occurrence of an undesirable situation (such as an expensive failure) will be likely. Depending on the availability of serviceable spares for that component, it might be removed soon after the condition is recognized, or the removal might be delayed for some time. In terms of control theory, the control of the shop work load may be viewed as a closed-loop control system with feedback and feed forward.

Part of the deterministic approach is the idea that over the life of a component an optimal point can be determined at which the component should be removed for reconditioning or discard. This point is determined by balancing the cost of an expected in-service failure against the cost of a preventive replacement. The analysis required is part of the standard repertoire of classical reliability theory. Implicit in this approach is the acceptance of in-service failures as a fact of life, and the assumption that it is permissible to determine the "best" rate of such failures on the basis of economic considerations. To reduce the rate of in-service failures the replacement age may be reduced or the reliability of the component (i.e., decrease the failure rate during the early part of the life) may be increased. Both alternatives may be costly; the second one is frequently referred to as gold-plating.

Underlying the approach that replaces a component on the basis of age are two important assumptions that often go unnoticed:

- The lives of components at failure are assumed to be identically distributed, independent random variables and
- The age of the component is the only information available to warn about increasing likelihood of a failure.

Neither of these conditions is true in most practical situations. Over the life cycle of a system the age at failure of components may undergo significant changes as the design evolves and maintenance practices and operating conditions are modified. Also, for most components, much better indicators of increasing wear than the age of the component are available. Many of these involve nothing more than observing the performance of the component during operations. Others may involve simple measurements or possible nondestructive testing methods. Thus the life of an individual component is differentiated from the universe of lives of like components. Although a probability density function of the life of the component at failure cannot be provided, the point at which the probability of a failure starts to increase can be identified. Thus any individual component may be replaced when its individual probability of failure dictates replacement. The results, clearly, are an increase in the average age at removal for all components and a decrease, or possible elimination, of the probability of an in-service failure. Provided that identifying the point of increasing probability of a failure is not too expensive, this approach clearly dominates the policy of replacement on the basis of age.

An additional difficulty associated with the deterministic approach is that it is based on statistics of past behavior of a component. By the time sufficient statistical information becomes available, a component may be well into the middle of its life cycle. Thus, unless prohibitively expensive testing precedes the introduction of a system to service, the deterministic approach may not be practical at all in real transit systems.

The point of departure for the dynamic approach is considerably different from that of the deterministic approach. Instead of searching for an optimal point in a parameter space, given a fixed policy (i.e., replacement on the basis of age), it concentrates the search in the policy space. The subsequent optimization of parameters for a selected policy usually turns out to be rather simple and is often dictated by circumstances. In many cases, economic results as well as other performance measures are little changed as long as the parameters are selected within reason.

Maintenance programs in the dynamic approach are developed through logical analysis, following the branches of a precisely defined decision tree. The first part of the decision tree is devoted to analyzing the consequences of a failure and to determining whether the occurrence of the failure can be detected by the operator. After that, possible maintenance tasks are explored, starting with condition monitoring, and age replacement is considered only as a method of last resort.

The decision tree approach was first developed by airlines (7) where it is known by the acronym MSG. The armed services have also widely embraced this approach. It is known there as reliability centered maintenance (RCM).

Although the basic structure of the decision tree is always the same, the details of it have to be carefully adjusted to the type of system under review. Figure 3 shows an adaptation for an analysis of transit buses.

One of the objectives of the dynamic approach is to eliminate life threatening failures altogether, at least as far as that is possible by the design of

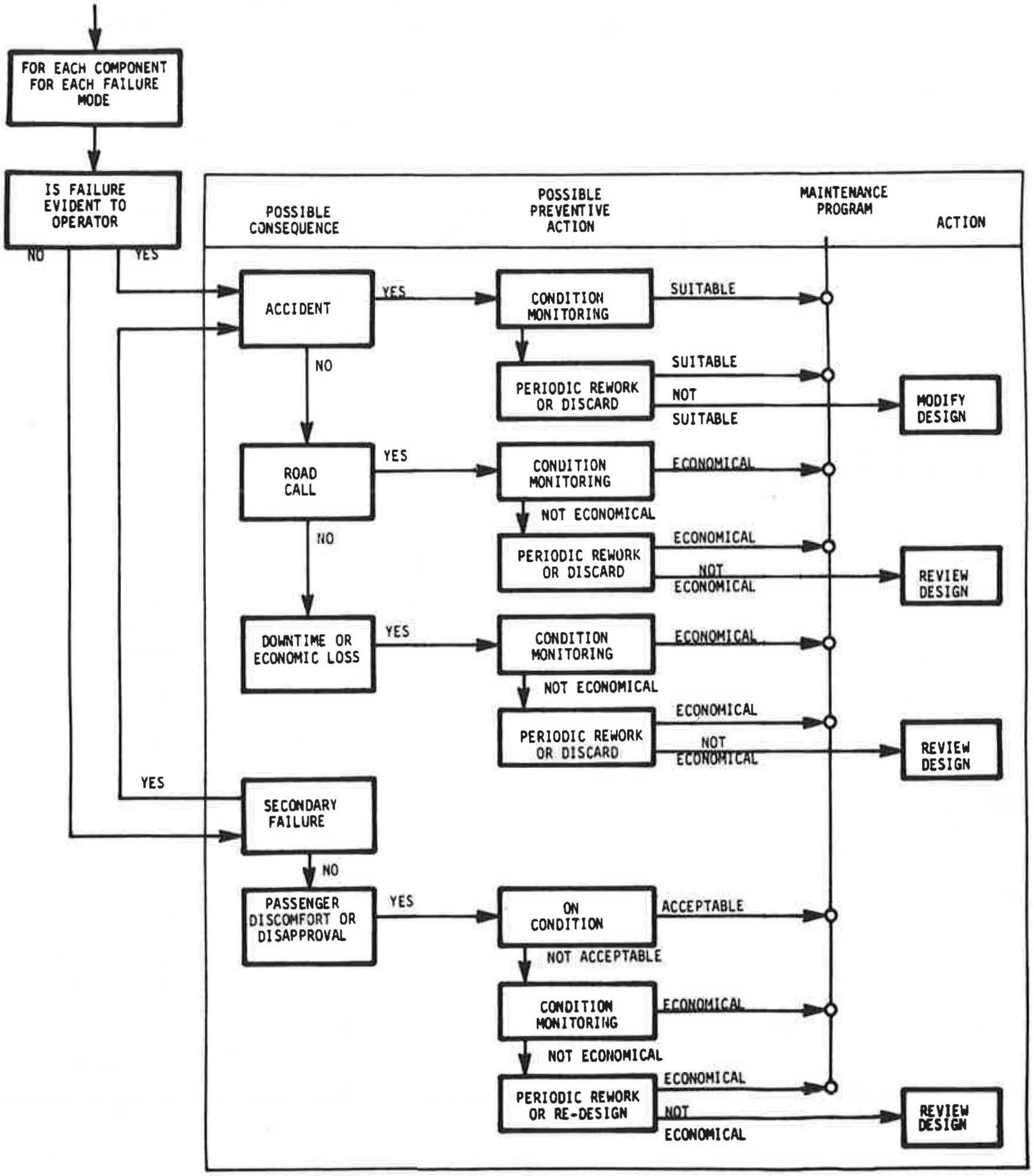


FIGURE 3 Decision tree for analyzing transit bus components.

the system. When it is not possible to achieve a satisfactory level of safety through maintenance measures, the analysis points out that a modification of the system is required to meet the objective. This analysis, together with the type of information that becomes available through an organized condition monitoring process, provides momentum for ongoing product improvement.

It is often assumed that condition monitoring requires complicated and expensive instrumentation either in the shop or on board the vehicle. However, much condition monitoring can be done by the operator or by servicing personnel during their normal contact with the vehicle. As an example, in airlines almost 50 percent of all corrective maintenance work is triggered by crew reports. The need for the other 50 percent is identified by mechanics during scheduled inspections (8). Experience with extensive onboard instrumentation has generally been disappointing. Apart from the fact that it often generates more information than can be processed effectively, the instrumentation and associated wiring may require expensive maintenance. Failures of them may lead to unreliable signals that may cause unnecessary maintenance to be performed. For examples of on-board instrumentation see Birkler and Nelson (9) who deal with turbine engines for military aircraft, and Casey (4) who describes an experiment for transit buses. In general, the most successful on-board diagnostic systems use signals that are already available for purposes of control. In transit buses, the electronic control units for engines and transmissions appear to have a strong potential for such use.

DESIGN OF A DYNAMIC MAINTENANCE SYSTEM

Many of the elements of the dynamic approach to maintenance can be implemented strictly within the boundaries of current maintenance organizations. However, these elements implemented in isolation would most likely produce only minor improvements in the performance of maintenance, at least compared with what would be made possible by a full implementation of the dynamic approach. The reason is that many of the problems of maintenance today stem from badly defined interfaces with other functional areas of the company and from the fact that the responsibility for some areas that constitute an integral part of the maintenance function is located outside the maintenance department.

A proper implementation of the dynamic approach to maintenance thus requires the attention of the entire company and the active support of top management. In most transit companies introduction of the dynamic approach will mean a modification in the corporate culture. This will not be easy and can only be done in an evolutionary process from within each company. Change agents brought in from the outside can be expected only to guide this process. In the following discussion, the key steps in the development of a dynamic maintenance system will be treated briefly. Excluded from the discussion is the development of a maintenance program, which was discussed in the third section.

Overall Optimization of the Maintenance System

The mission of a transit company requires that a predetermined number of buses (the "active fleet") be in good condition and running without en route breakdowns during the time the schedule calls for. Any bus that is not in the active fleet at least part of the day is an extra expense to the system. Some of these buses may need to have maintenance work performed on them. The rest may be justified as standbys for charter or other purposes. The investment cost for the reserve buses needed for maintenance constitutes an integral part of the maintenance expenses in the same way spare repairable components do. Holding maintenance accountable for these costs and for the cost of en route breakdowns will give maintenance personnel an incentive to define their work in such a way that it is optimal from the point of view of the entire transit system.

Overall optimization requires that all resources of the company be used for the purpose of effective maintenance. For example, although the bus operator is part of a different department, he has to be made an integral part of the condition-monitoring system.

Planning and Control Methods

Management of maintenance has to be structured so that maximum flexibility (i.e., response capability to unforeseeable work loads) is attained. Because the human ability to recognize patterns, relationships, and unique conditions is far superior to that of a computer, at least for a long time to come the human will be a central element in maintenance.

The development of planning and control methods, especially computerized ones, has to be sensitive to the special circumstances of a maintenance environment. It also has to recognize the needs of humans for satisfying work. Radically new concepts may have to be embraced. An adaptation of systems and methods developed for production systems, for example, will not suffice.

Materials Management

The overriding concern in materials management is the relatively small size of the problem, which does not justify big expenditures but which also permits people to have a good grasp of the overall situation. The most promising approach appears to be bringing experts together for decision making. This can be expected to lead to considerable side benefits in the form of comparisons of work procedures among mechanics, which will lead to improvements in overall procedures.

There are two categories of bus components, the repairable components, which, when they require work, are exchanged against like components and worked on independently of the bus, and the expendable components, which are only removed from the bus when they are to be discarded. For each component a determination has to be made of whether it should be treated as a repairable or as an expendable component. Treating it as a repairable component may lead to substantial savings in bus downtime. On the other hand, the cost of setting up and managing the float has to be considered. Also, removal of the component and replacement with a serviceable one may require considerable time and thus be expensive. These expenses have to be traded off for each part against the benefits of reduced bus downtime.

For each repairable component the optimal float level has to be determined. The float has to assure that, in spite of the randomness of the removal process and the repair process, the frequency with which the need for a serviceable component cannot be satisfied is below some small level. However, because repairs can be accelerated and, to some extent, removals delayed when the level of serviceable parts is low, this is by no means an easy problem to solve. Because, in reality, many kinds of parts and in some cases buses also compete for the same shop capacity, this problem becomes quite complex. Considerable work on this subject has already been done in aviation. For an overview of this work, see Etschmaier (10). This work will have to be adapted to the special situation in transit maintenance, especially to the small scale of the problem.

Methods also have to be developed for scheduling component repairs through the shops. This issue ties materials management directly to the planning and control methods discussed previously.

For all components and parts, future usage has to be predicted for the short as well as the long range. The number of parts required for maintenance of transit buses is small enough that automatic forecasts are not necessary. Instead, it is possible to review past usage patterns for each part and to determine how these patterns are tied to different kinds of maintenance activities. Given a forecast of future maintenance activities, this information can immediately be turned into forecasts of parts usage. The forecasts are best developed in conference by teams familiar with the details of design and maintenance procedures, probably lead mechanics, foremen, and parts men. They should be assisted by formalized procedures in the form of worksheets, either on paper or computerized. Computerization could relieve them of some of the number-crunching activity that is unavoidable in this process.

Access to spare parts for mechanics has to be made as immediate as possible, without creating chaos. In a small shop the effort devoted to parts control can easily become excessive. Reorder procedures for expendable components and parts have to be developed.

Mobilization of Personnel Resources

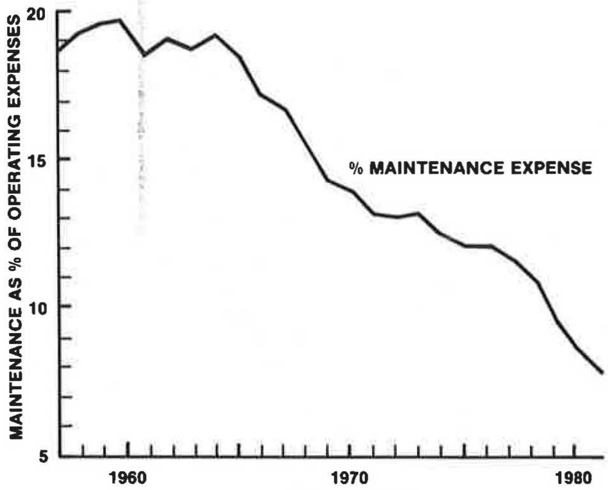
The most significant factors that currently inhibit the effectiveness of maintenance labor and in some properties lead to worker apathy and resignation are adversity in the labor-management relationship, restrictive work rules, inconsistencies in mechanics' training, and the absence of a clear definition of purpose visible to the workers.

The problems are extremely complex and there are no easy or fast answers. Certainly there are no answers that can be imposed on a transit system from the outside. Instead, solutions have to be found for one system at a time by immersion in the situation and the special problems faced by the system. What is needed is skill and leadership, vision and sensitivity, and above all a fundamental sense of fairness. Solutions have to be found by working with workers and their unions and listening to them as fully emancipated partners in this process. The approach taken has to be based on solid realism, but also on a firm belief in, and respect for, the quality of workers as well as sensitivity to their needs and feelings. There is little room for the application of fads or isms, nor should this be a playground for ivory tower research. Mobilizing the personnel resource of a property almost certainly requires the temporary infusion of a change agent from the outside, but whoever he may be, he must have a full grasp of all aspects of maintenance and be willing to "get his hands dirty." He must, of course, also have the full support and understanding of all levels of management. The line between success and failure in such an undertaking is narrow, but the potential for improvement and the sense of reward for all involved can be tremendous.

CONCLUSIONS

The systems approach provides an opportunity to reexamine the performance of maintenance in a transit system and to redefine the relationship between maintenance and the rest of the company. Clearly, it is not something that can be imposed on a company from the outside. Instead, it requires a long process of evolution from within that has the full support and understanding of all levels of management. If this process is to succeed much hard work and dedication by many people within a company are required. This work appears fully justified because it can be expected to produce significant improvement in the performance of maintenance and to halt the escalation of cost of the maintenance department as currently defined. Significant reductions of the cost of the overall maintenance function as defined in this paper will occur with certainty.

To provide an indication of just how significant the savings through the application of the systems approach may be, Figure 4 is a graph [reproduced from Ralf (11)] showing maintenance cost as a percentage of total operating cost in airlines between 1957 and 1981. The systems approach was introduced gradually beginning in the early 1960s and was fully implemented around 1970. During this period maintenance expenses decreased from around 19 percent to 12 percent of total operating expenses. They have continued to decrease since then; however, some of the decrease has to be attributed to the increase in fuel prices. Although the authors are not suggesting that the success of airlines maintenance can be duplicated in transit, they expect the results to be convincing.



Soruce: Ralf (1982)

FIGURE 4 Experience of U.S. airlines (*11*).

ACKNOWLEDGMENT

The work reported in this paper was performed while the first author was serving on a Faculty Fellowship Grant at the Transportation Systems Center of the U.S. Department of Transportation in Cambridge, Massachusetts. The work was conducted in the Planning Methods Division under Donald E. Ward and sponsored by the Methods Division, Office of Methods and Support, UMTA, Granville E. Paulus, Chief. The collaboration of Cornelius Harrington, Transportation Systems Center, is gratefully acknowledged.

REFERENCES

1. R. Malec. Bus Maintenance: Keeping the Lid on. Presented at APTA Annual Meeting, Oct. 1983.

2. DOT Needs Better Assurance that Transit Buses are Maintained. Report GAO/RCED-83-67. General Accounting Office, 1983.
3. M.M. Etschmaier and G. Anagnostopoulos. Dynamic Maintenance for Rail Transit. Staff Study, SS-66-U. 3-05. Transportation Systems Center, U.S. Department of Transportation, Cambridge, Mass., 1983.
4. R.F. Casey. The Automated Bus Diagnostic System Demonstration in New York City. Staff Study SS-64-U. 3-1. Transportation Systems Center, U.S. Department of Transportation, Cambridge, Mass., 1983.
5. M.M. Etschmaier. Review of Transit Bus Maintenance in the United States. To appear in Transportation Research, 1984.
6. P.J. Ringo. Transit Operations--The Manager's Perspective. In G.E. Gray and L.A. Hoel, eds., Public Transportation: Planning, Operations, and Management, Prentice Hall, Englewood Cliffs, N.J., 1979.
7. F.S. Nowlan and H.F. Heap. Reliability-Centered Maintenance. Dolby Access Press, n.p., 1978.
8. F.S. Nowlan and H.F. Heap. Reliability-Centered Maintenance. Proc., 1978 Annual Reliability and Maintainability Symposiums, 1978.
9. J.L. Birkler and J.R. Nelson. Aircraft Turbine Engine Monitoring Experience: An Overview and Lessons Learned from Selected Case Studies. Report R2440-AF. Rand Corporation, Santa Monica, Calif., 1980.
10. M.M. Etschmaier. Contributions of Operations Research in the Area of Maintenance and Inventory Control of an Airline. Technical Report No. 12. Department of Industrial Engineering, University of Pittsburgh, Pa., 1973.
11. J.E. Ralf. Reducing Maintenance Cost--Reliability, Innovation, and Regulatory Relief. Presented at Engineering and Maintenance Forum of the Air Transport Association of America, Minneapolis, Minn., 1982.

The paper represents the views of the authors and does not necessarily reflect the views of the Transportation Systems Center or UMTA.

Publication of this paper sponsored by Committee on Bus Maintenance.

Management Information Systems for Small, Fixed-Route, Fixed-Schedule Operators

JOHN COLLURA and PAUL McOWEN

ABSTRACT

Guidance is provided for managers of small, fixed-route, fixed-schedule services who are considering the purchase of a microcomputer and the necessary software for management information purposes. The major management-related functions of such services, which require the tabulation and analysis of data, are reviewed in detail and categorized into six groups: (a) administrative, (b) planning, monitoring, and evaluation, (c) operations management, (d) materials and equipment ordering and inventory, (e) maintenance, and (f) financial management. Following this review, source forms for the actual collection of the data are proposed and management reports for each function are suggested. Reference is also made to a set of criteria and standards to assist managers in the selection of the type of microcomputer and the required peripherals and software. To illustrate the use of these criteria and standards, three alternative hardware and software systems are formulated. Each system is intended to aid in all information management functions, to accommodate the processing of the data that have been entered from the source forms, and to generate the necessary reports. Each system consists of "off-the-shelf" software (including a data-base manager and some application programs and report generation capabilities). The hardware includes the most popular and widely used mircrocomputers and printers. Each system can be purchased for a total cost of approximately $10,000 to $12,000.

The use of microcomputers is becoming prevalent in many areas of transportation (1). The first phase of the research consisted of a broad-based and detailed review of a representative group of existing, automated, management information system (MIS) applications, the development of an evaluation framework, and the use of this framework to identify deficiencies among the existing MISs (2). MISs were studied at nine different transit sites in several different areas of the country. Sites were selected to represent widely varying fleet sizes, service area characteristics, and modes of service. In addition, a number of non-site-specific software and hardware packages were reviewed, including several within the public domain that were developed with public funds and several that are available commercially from private companies.

The existing MISs were evaluated in terms of their capabilities, limitations, ease of use, and relative costs. As a result, it was observed that MISs are in use in transit systems of all sizes and all modes. However, most of the MISs reviewed were not comprehensive in that they served one or more MIS functions but not all of the major management information needs. Those MISs that were the most comprehensive were relatively expensive and designed for minicomputers and for use in larger transit systems. The major deficiency observed was the absence of an affordable, comprehensive MIS application for small, fixed-route transit systems (30 vehicles or fewer).

The results of continuing research to address this deficiency are presented in this paper. All major MIS functions relating to systems of this size were reviewed in detail. Original coded source forms were developed for these functions; the data elements included correspond to reporting requirements, cost-effective maintenance management, and operational, billing, and accounting needs. Criteria and standards were then developed to aid in the selection of hardware and software that could be used by small, fixed-route, fixed-schedule transit operators with varying service characteristics and data priorities. Several software and hardware alternatives that meet all standards at a total cost of approximately $10,000 to $12,000 were assembled.

MANAGEMENT FUNCTIONS

Before any hardware or software is selected, it was necessary to define and delineate all significant MIS functions for small, fixed-route, fixed-schedule services. This effort involved a synthesis of existing literature on transit management and operations (3) as well as a number of meetings with the managers of four small transit systems in Massachusetts. As a result of this effort, the MIS functions were grouped into six functional categories:

- Administrative;
- Planning, monitoring, and evaluation;
- Operations management;
- Materials and equipment management;
- Maintenance; and
- Financial management.

An explanation of each function and a list of the types of associated reports appeared in the February 1984 issue of Bus Ride (4). Examples of reports for each function may be found elsewhere (5). Some of these reports were submitted to federal and state transportation agencies as regular reporting requirements. Other reports have been borrowed from several non-site-specific and site-specific software packages.

SOURCE FORMS

The development of source forms for gathering and tabulating data for the various management functions included a review of federal and state data reporting requirements. It should be noted that the required level of UMTA and state financial and nonfinancial reporting standards (6) was used as a base to which other administrative, planning, monitoring and evaluation, operations, materials and equipment, maintenance, and internal financial data elements were added. A list of the source forms and some projections of the potential memory storage requirements for a small, urban, fixed-route, fixed-schedule service is given in Table 1. Some forms would be completed daily; others would be used less frequently (e.g., weekly, yearly). To estimate the amount of storage capability required for each source form, the maximum number of characters on each form was determined and multiplied by the corresponding frequency of use. These estimates were then added to yield a total of more than 5 million bytes of financial and nonfinancial data produced annually. Copies of the eighteen source forms may be found elsewhere (5).

The information tabulated from the source forms is intended to provide the required reporting data as well as useful "action" data to examine the fuel consumption or maintenance requirements of a particular vehicle, overdue safety inspections, and critical shortages in parts and equipment inventory. The source forms facilitate the collection of the most significant data needed by different transit systems. Those operations that do not require or desire certain data on a particular source form would have the option of leaving that data category blank.

The source data forms used in several site-specific packages and non-site-specific packages were reviewed and compared for content with the forms discussed previously. These source forms were also reviewed critically by the transit managers of the systems in Massachusetts. Finally, the data elements for each form were precoded for computer entry. These forms may be further revised or reformulated during the testing phase to include additional data or for more efficient data processing.

INFORMATION FLOW AND INTEGRATION

Another important aspect to consider is how information obtained for one function such as monitoring and evaluation interrelates with information about other functions such as financial management, inventory control, or maintenance so that a report can be prepared with data from two or more source forms. An example of this type of report would be one that reports a performance statistic, such as operating cost per passenger trip. The nonfinancial information (i.e., passengers) would be obtained from source form 6 and the financial data (i.e., expenses) would be derived from source forms 15 and 16. In simpler cases, information will flow primarily within one function; for example, number of accidents for a particular vehicle for a particular period. The importance of information flow and integration will be discussed further in the section on software development that addresses data base management.

It should be stressed that building and accessing a common data base to satisfy the various management functions is critical to the development of a useful comprehensive package. This capability will help to streamline data collection and processing and reduce costly and time-consuming, multiple, manual handling of the same data within different functions.

HARDWARE AND SOFTWARE CRITERIA AND STANDARDS

With clear definitions of the major MIS functions, the necessary data elements, and an understanding of how the information is interrelated among the different functions, criteria were established to aid in the selection of software and hardware. Minimum requirements (standards) were also proposed for use with these criteria. These criteria, minimum re-

TABLE 1 MIS Source Forms and Memory Storage Requirements

Form #	Form Name	Use of Form	Frequency of Use	Max. Char./Form	# Char. of Memory Required
1	Employee Record Card	Personnel records	150 forms permnt.	123	18,450 permanent
2	Payroll Card	Wages & hours	150 forms/week	36	280,800 / yr.
3	Accident Report	Accidents	30 forms/yr.	63	1,890 / yr.
4	Incident Report	Complaints	75 forms/yr.	30	2,250 / yr.
5	Route/Run Set-Up	Route/run definition	100 forms permnt.	1158	78,840 permanent
6	Daily Vehicle/Route	Driver's daily log	50 forms/day	493	4,253,796 / yr.
7	Vehicle Master Rec.	Vehicle inventory	36 forms permnt.	102	3,672 permanent
8	Fluids Constants	Fuel & oil prices	1 form permnt.	43	43 permanent
9	Maint. Fluids	Record fuel metering	156 forms/week	18	144,720 / yr.
10	Maint. Service	Servicing & repair	100 forms/month	554	664,800 / yr.
11	Item Description	Parts inventory	1200 forms permnt.	188	133,824 permanent
12	Parts Issue/Request	Track & order parts	75 forms/week	19	72,000 / yr.
13	Parts Vendor Constnts	Vendor name & address	2 forms permnt.	800	1,600 permanent
14	Fares Constant	Fare types & rates	1 form permnt.	21	21 permanent
15	Purchase Request	Authorize purchases	300 forms/yr.	298	89,400 / yr.
16	Disbursement Log	Track disbursements	87 forms/yr.	235	20,445 / yr.
17	Invoice	Request reimbursements	420 forms/yr.	42	17,640 / yr.
18	Funds Receipt	Track receipts	420 forms/yr.	28	11,760 / yr.
				TOTAL:	5,795,951 / yr.

ASSUMPTIONS

1. UMass system
2. 150 employees
3. 30 accidents/yr.
4. 12 routes
5. 600 daily runs academic yr.
180 daily runs summer
60 daily runs weekends
6. 75 incidents/yr.
7. 20 stops/run maximum
8. 36 vehicles
9. 30 buses/day academic yr.
3 buses/day weekend
9 buses/day summer
10. 100 repair orders/month
11. 1200 parts stocked
12. 12 major parts vendors
13. 15 parts/day issued
14. fare mechanism assumed
(available as option)
15. 435 checks issued/yr.

quirements, and standards are presented in detail elsewhere (5).

THREE ALTERNATIVE HARDWARE AND SOFTWARE SYSTEMS

Alternative packages that are consistent with the criteria and standards were assembled. In the interests of affordability, ease of use, and replicability, newly developed "off-the-shelf" application software programs were examined. This examination produced the three candidate software packages given in Table 2 along with the range of hardware that could be used with these packages. Central to the three alternative software and hardware configurations are the respective relational, data base management programs: Logiquest, D-Base II, and Micro-Rim. Another possible alternative might be the RIM package that is in the public domain. RIM was developed by the National Aeronautics and Space Administration and is in use on minicomputer systems at the U.S. Department of Transportation Transportation Systems Center. RIM was altered for use with a microcomputer by Micro-Rim, Inc., and there were changes made to this software package that allow the program to operate with the smaller, less powerful microprocessors. The use of hard disk external data storage was also specified.

Other interesting microcomputer projects in progress were discovered during the second phase (7). The RUCUS run-cutting package is being altered for use on a microcomputer, and a microcomputer vehicle maintenance package is being explored by the U.S. Department of Transportation Transportation Systems Center. Another run-cutting program has been written in D-Base II for the Seattle, Washington, Metro System. The Dodotrans II transportation planning programs developed at the Massachusetts Institute of Technology also operate on microcomputer hardware. The Capitol District Transit Authority in Albany, New York, uses a microcomputer with sample service data to estimate ridership and other information for system monitoring and evaluation (8).

Although much has been accomplished at the larger transit systems to aid with specific tasks and provide responsive analysis of particular models, there is a need for testing a truly comprehensive MIS for the small operator. Past and current efforts in the area of automated MIS development for paratransit by the private sector, the U.S. Department of Transportation Transportation Systems Center, the Massachusetts Executive Office of Transportation and Construction's 16-B-2 Program, and others have led to the emphasis on research on the needs of the small, fixed-route system.

CONCLUSIONS

As a result of this research, it has been determined that commercial software is available "off-the-

TABLE 2 Recommended Alternative Software and Hardware Packages for Phase II Testing

		Alt. #1	Alt. #2	Alt. #3
Software:				
	- Operating System			
	- Data Base Manager:	Logiquest III	D Base II	Micro-rim
	- DBM Language	Pascal	D Base II	Fortran
	- DBM Technical Specs	55 fields/rec, use mult. files, 15 search criteria, password protection, conditional expressions, macro processing, 8 pages/rec	65,000 char/file, multiple file usage, macro processing, 10 search criteria	127 fields/database 20 files/database use mult files 254 char/field
	- Resident Language	Pascal	Basic	Fortran
	- Applications programs to be used	Geniledger, Accounts Pay/Rec, Inven Control, Procalc, Text Processing, Mail System	Word processor, Dutils, Quickcode	Wordstar processor (self-programmed)
	- Total Software Cost	$ 1,890	$ 1,500	$ 1,035
Hardware:	- Manufacturer Alternatives	IBM personal, TRS-80 Model II, Altos	Apple II+ (w/z-80 card), Northstar Advantage, TRS-80 Model II	Apple II+ (w/z-80 card), Northstar Advantage, TRS-80 Model II
	- Typical Peripheral Configuration*	5M Hard disk, letter printer (64+ K computer)	5M Hard disk, letter printer (64+ K computer)	5M Hard disk, letter printer (64+K computer)
	- Approximate Hardware Cost (Typical Configuration)	$ 9,000	$ 9,000	$ 9,000
Software/Hardware Approximate Total Cost (Typical Configuration)		$10,890	$10,500	$10,035

* Note: A variety of different types and qualities of printers, CRTs, and "hard" and "soft" disk peripherals are available and may be used with the various manufacturers computer alternatives in conformance with the minimum hardware standards.

shelf" that can be used with several popular microcomputer models for comprehensive information management for all major transit management functions for small and medium-sized fixed-schedule fleets. The total hardware and software cost of $10,000 to $12,000 appears to be reasonable with respect to typical budget levels for many transit systems with smaller fleet sizes.

The relative ease with which such an automated MIS can be implemented and the amount of staff retraining required are currently being determined during the on-going testing phase of the research. At this point, it is clear that familiarity with computer programming languages is not required of transit personnel, and it should not be necessary to hire new staff with previous computer experience to operate the automated MIS.

Unlike many existing microcomputer applications in transit, which use single-file data management software for a particular function such as inventory control or ridership analysis, the hardware and software combinations that are currently being tested have the capacity to access data from many different functional areas simultaneously so as to combine virtually any information that is collected within the transit program to produce useful management reports. The other unique feature of the package being tested is the ability to automatically interface the information in the data base with spreadsheet analysis programs for planning, with standard bookkeeping and accounting software, with text-processing programs, and with standard inventory control software.

The implementation of comprehensive, affordable, and easy-to-use automated management information systems should serve to simplify billing and accounting procedures and aid transit officials in complying with local, state, and federal reporting requirements, such as Section 15. It is expected that an improved ability to monitor transit performance will improve the quality of both short-term and long-term decision making regarding finances, routes, maintenance, and other elements of system operations and management.

ACKNOWLEDGMENTS

Appreciation is extended to the Contract Officer's Technical Representative, B. Paul Bushueff of the U.S. Department of Transportation Transportation Systems Center. His guidance and technical assistance were extremely valuable throughout the course of the project. The administrative assistance of officials from the U.S. Department of Transportation Office of University Research is also gratefully acknowledged--particularly the support of John E. Doyle, Jr., Theodore Higgs, and Wilbur Williams.

Participation of others who worked on the project must also be recognized, including contributions by the graduate students and consultants on the research team. In addition, the services of Japhet Nkonge, Associate Professor, North Carolina A&T State University, were instrumental in the development of the financial source forms, reports, and functional flow charts. The technical guidance provided by Conrad Wogrin, Director of the University of Massachusetts Computer Center; Russell Parker, computer analyst with ComputerMart in Waltham, Massachusetts; and David Stemple, Graduate Program Director for the University of Massachusetts, Computer Sciences Department, is gratefully acknowledged.

The support of individuals at local transit sites made an enormous contribution to the project, especially the contributions of William Barrett and Al Byam of the University of Massachusetts Transit System. Finally, the exceptional typing and editing of Sue Lee must not go unmentioned. Her work contributed greatly to the overall organization and readability of this paper.

REFERENCES

1. D. Ward, M. Couture, R. Allbright, and G. Paules. Automation in Public Transit Operation and Management: Update. In Transportation Research Record 854, TRB, National Research Council, Washington, D.C., 1982, pp. 24-30.
2. J. Collura, R. Bonsignore, and P. McOwen. Computerized Management Information Systems for Transit Services in Small Urban and Rural Areas. In Transportation Research Record 936, TRB, National Research Council, Washington, D.C., 1983, pp. 60-68.
3. J. Collura and D.F. Cope. Assessing User Needs in the Design of a Management Information System for Rural Public Transportation Services. In Transportation Research Record 854, TRB, National Research Council, Washington, D.C., 1982, pp. 67-70.
4. J. Collura and P. McOwen. Thinking About a Computer for Your Bus Company? Bus Ride, Feb. 1984, pp. 76-78.
5. J. Collura et al. A Management Information System for Rural Transit Services--Interim Report on Phase I. DTRS5681-C-00019. University of Massachusetts, Amherst; Office of University Research, U.S. Department of Transportation, Oct. 1982.
6. Urban Mass Transportation Industry Uniform System of Accounts and Records and Reporting System. UMTA, U.S. Department of Transportation, Jan. 1977.
7. Microcomputers in Transportation Information Source Book. U.S. Department of Transportation, 1982.
8. J. Reilly. Microcomputer Use at the Capitol District Transportation Authority. Capitol District Transportation Authority, Albany, N.Y., Aug. 1982.

Publication of this paper sponsored by Committee on Rural Public Transportation.