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Urban Public Transportation: Planning and Service Operation Issues

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Transportation Research Record 1108

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Contents

Foreword

Nine papers relating to transit planning and operations comprise this publication. Some are condensations of more extensive work by the various researchers.

The continued financial problems of the public transportation industry has accelerated the search for more cost-effective ways of delivering transit services. The first two papers in this Record address the topic of service contracting, which is being used by many transit agencies to cut costs. Teal's paper presents a model to estimate cost savings and Pickrell concludes from his research that there appears to be little risk that widespread contracting out of transit services will produce increased deficits for current operators.

Transit operating issues are the subject of the next three papers. Talley and Becker analyze the distribution of on-time performance of bus service, while Furth describes possible schedule coordination modes to cope with the common practice of short turning certain runs part of the way along a bus route rather than continuing the run to the route terminus. Another paper, by Oxley, examines the incidence, causes, and methods of ameliorating assaults on bus staff in Britain. Although U.S. crime against bus drivers has diminished considerably since the adoption of the exact fare payment system, transit agencies can learn from the British experience, which shows ways of reducing assaults.

Stopher et al. document the development of a new cost-allocation model that differs from the traditional ones by separating costs into fixed and variable components and by using multiple step functions that reflect the increments of cost or savings. The model is compatible with the UMTA Transportation Planning System (UTPS) models. Each of the model tests indicated satisfactory performance.

Hamberger and Chatterjee report on a study conducted in Nashville, Tennessee, to determine the effects of fare and other factors on transit usage. It was found that the elasticity coefficient for fare was higher than those revealed in other studies.

In another paper, Dehghani et al. report on the overseas application of microcomputers for a transportation planning and engineering design project. In the last paper of the Record, Horowitz describes a procedure for applying multipath trip assignment to transit networks. The procedure extends an existing traffic assignment algorithm. The tests revealed the assignment procedure to be free of the problems previously associated with applications of stochastic multipath assignment in automobile networks.

Estimating the Potential Cost Savings of Transit Service Contracting

GENEVIEVE GIULIANO AND ROGER F. TEAL

The continued financial problems of the public transportation industry have motivated a search for more cost-effective ways of delivering transit services. Service contracting—the contracting of public transit services to private providers—has emerged as one of the most promising alternatives. Existing evidence suggests that service contracting could reduce public agency cost by 10 to 50 percent. If service contracting were implemented throughout the public transit industry, services currently provided by public agencies would be shifted to private provision. However, little is known about how such service shifts would affect transit service costs, and whether significant cost savings would occur. An assessment of the cost-savings potential of transit agency service contracting is presented in this paper. A cost model based on the concept of avoidable cost is used in a series of case studies to generate estimates of potential cost savings resulting from contracting various quantities of transit service. Research results showed average cost savings of 23 percent for the contracted service. These savings are equivalent to about 4 percent of the transit agency's total operating cost. Cost savings depend on a number of factors, but are roughly associated with the size of the transit agency. Cost savings for small agencies are insignificant and can be negative, while savings for agencies larger than 250 vehicles typically range between 5 and 7 percent of total operating cost when 20 percent of existing service is contracted.

The continuing financial problems of public transportation have motivated a search for more cost-effective ways of delivering transit services. This search has proceeded in two directions: (*a*) improving the internal cost efficiency of the services directly operated by transit agencies, for example by using part-time drivers, reducing absenteeism, and introducing computer technology; and (*b*) focusing on alternatives to the current service delivery system.

Although internal reforms are desirable, they rarely produce significant cost savings. For example, the use of part-time drivers, which is expected to be a major cost savings innovation, has been widely implemented but has led to relatively minor cost reductions (*1*). Equally significant is the fact that purely internal changes do nothing to address a fundamental factor behind the industry's cost escalation, namely the absence of competitive forces to keep costs under control. As a subsidized, monopoly-organized industry at the regional level, transit agencies face no economic incentives (beyond the simple availability of subsidies) to keep costs low. Not surprisingly, costs have risen at a rate exceeding inflation for the past 2 decades.

Various forms of private sector involvement have been advocated as a means for injecting competition into the transit industry, thereby fostering more cost-effective service (*2*). Service contracting, the provision of transit services by private operators under contract to public agencies, has emerged as one of the most promising alternatives. Existing evidence suggests that transit contracting can provide services at costs 10 to 50 percent below public agency cost levels (*3*). Service contracting is widely employed for small local transit services, but its use among medium and large transit agencies is limited (*4*). Opportunities may therefore exist to realize large cost savings by wider use of contracting. Given transit's current fiscal environment, it is critical that the cost savings potential of this strategy be carefully evaluated.

Careful evaluation requires accurate estimates of potential cost savings for different levels of service contracting. It is likely that any significant implementation of contracting would include service currently provided by public agencies. However, there is little information available on the possible effects of contracting existing transit agency services. Institutional constraints [local labor contracts, as well as Section 13 (c) of the Urban Mass Transportation Act] severely restrict the transfer of public agency-operated service to private contractors. Indeed, there is only one known case—that of Tidewater Transit—in which such a service transfer has been accomplished. All other service-provider changes have occurred in situations where the public transit operator involved was acting as a contractor to a higher level funding agency (*3*).

Given the lack of actual experiences with this form of service contracting, a method for estimating potential savings is necessary. Presented in this paper is an assessment of the cost savings potential of transit agency service contracting based on the application of a new cost estimation model. Research reported here is part of a larger UMTA-sponsored project on the economic and institutional impacts of transit service contracting. Paper topics include (*a*) a discussion of the research problem in the context of previous research; (*b*) the modeling approach; (*c*) results of the model applications; and finally (*d*) an assessment of the cost savings potential of transit service contracting.

THE RESEARCH PROBLEM

An assessment of the impact of transit service contracting depends on the institutional structure of transit service provision. There are two general institutional forms for public transit in the United States. One form may be termed the consolidated

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agency, in which both funding and operating authority are vested in a single public agency. Regional transit authorities are examples of consolidated agencies. The second form may be termed the operating agency. A public operating agency provides service, but receives funding from another nonoperating entity. For example, counties, cities, and more recently, regional transportation boards may act as nonoperating agencies and pass public funds to local operating agencies. Contracting with private providers has occurred primarily in areas where the latter institutional form exists. Among consolidated agencies, contracting with the private sector has largely been limited to demand–responsive operations and occasionally to new services. Contracting implies the broker concept in the case of transit authorities: the agency retains responsibility and control of the service, but shifts operation to the private provider. In contrast, when funding and operating authority are split, the funding agency is, in effect, already a broker, and the service shift is simply from a public to a private provider. In both cases, cost savings depend critically on the changing role of the public operating agency.

Neither simple comparisons of public versus private costs nor traditional cost allocation approaches are appropriate for the estimation of potential cost savings of contracting existing services. Public–private comparisons give correct estimates of savings to a third party funding agency, but fail to incorporate cost impacts on the public operating agency. For example, if a county contracting with the regional transit district for service at $50 per vehicle hour decides to go out to bid and finds a private operator willing to provide the same service at $40 per hour, savings will be 20 percent because the country's responsibilities with respect to the service have not changed. However, if the transit district performs the same exercise (assuming all costs are the same), it will not necessarily save 20 percent because its responsibilities with respect to the service have changed. Although it formerly had both administrative and service functions, the transit district retains the administrative function under contracting. Thus, savings for the transit district will be less than 20 percent.

Use of fully allocated cost estimates is not appropriate for two reasons: (*a*) if the transit agency retains some responsibility for the service, then certain costs will remain even in the long run, and cost allocation approaches will tend to overstate potential cost savings; and (*b*) cost allocation models involve implicit assumptions that costs respond in the same manner to both service increases and decreases, and that all costs are affected equally by the service change. Although these assumptions are conceptually reasonable, the nature of the transit service production process suggests this may not be the case. Specifically, the divisibilities of transit inputs (labor and vehicles), and the relationships of factor inputs in production processes are such that reductions in output may not result in corresponding reductions of all inputs.

The research problem, then, is to determine how transit agency operating costs change when a portion of service is contracted, and to determine a basis for comparing public and private operator costs. Costs to be considered depend on the assumptions made regarding service contracting arrangements. Significant portions of overhead or administrative costs, such as planning and marketing, may not be reduced when service is contracted. The appropriate comparison is between the transit agency costs that are reduced as a result of service contracting (net of any additional costs generated by the contracting), and the costs incurred by the private operator in providing the service. These transit agency reduced costs are the incremental costs of not providing the service, and are termed avoidable costs.

Several studies of the cost impacts of transit service contracting have been conducted. A variety of methodological approaches have been utilized in these studies, generating a wide range of results. For example, a study of express commuter services in the Los Angeles region predicted contracting cost savings of about 50 percent. A fully allocated cost model was used in the study, and no adjustments were made for the administrative and other costs that would not change under contracting (*5*). A comparative study of unit cost differences between public and private express bus service estimated cost differences ranging from –11 to 43 percent, depending on route length and vehicle utilization assumptions (*6*). Both public and private costs were based on cost allocation models.

A different approach was taken in a Boston study. In this case, the cost comparison for a set of express bus routes was between the direct (variable) transit agency cost and the full private agency cost (*7*). The justification was that the service reduction was so small that it would have no impact on the fixed costs of the transit agency, but the private operator would incur full incremental costs in providing the service. Study results indicated that cost savings would occur only if the transit agency retained ownership of the vehicles.

One of the most detailed cost studies was conducted by McKnight and Paaswell (*8*). Its purpose was to determine possible contracting cost savings for the Chicago Transit Authority (CTA). A modified cost allocation approach that distinguished between fixed and variable costs was used to estimate CTA cost reductions. Because of the marginal nature of the contracting options considered, all administrative and fixed facility costs were assumed fixed. The procedure also distinguished between short-run and long-run cost reductions. The study indicated savings ranging from 15 to 60 percent, depending on specific service characteristics.

MODELING APPROACH

The purpose of this research was to develop a methodology for estimating potential cost savings that would be applicable for a wide variety of service alternatives. The first step was to develop a set of assumptions regarding feasible service arrangements. Recognizing current institutional and organizational constraints to contracting existing transit services, two initial assumptions were made:

1. The scope of contracting alternatives is limited by the employee attrition rate (approximately 5 percent per year) because the replacement of transit agency employees by private service providers is essentially precluded if federal subsidies are involved; and
2. Service delivery options that minimize the need for cooperative action between the operating personnel of public and private operators are preferable.

For the purpose of estimating cost impacts, two time horizons are identified: the short run (1 to 2 years); and the long run (approximately 3 to 5 years). Given the first assumption, long-term contracting options are limited to approximately 20 percent of total existing service. In view of the second assumption, the route was selected as the unit of service to be contracted.

The Transit Cost Model

The transit cost model is an engineering-type model and is based on factor inputs (e.g., labor, maintenance, administration). Costs are allocated to input categories, and the change in cost due to a change in service is estimated for the resulting changes in input categories. The model has both a short-run and long-run component. In the short run, it is assumed that only the direct service costs—driver cost; fuel, oil, and tires; and scheduled maintenance and servicing—are avoidable. In the long run, avoidable costs are determined by contract service arrangements. The cost model is based on the following set of assumptions:

1. The transit agency supplies the vehicles and retains responsibility for vehicle insurance;
2. The private operator maintains the vehicles;
3. The transit agency retains responsibility for service system planning, marketing, public information, and general administration;
4. The transit agency retains all fare revenue; and
5. The transit agency retains responsibility for all fixed facilities.

All cost elements corresponding to functions assumed to be retained by the transit agency are fixed in the long run.

The transit cost model consists of a series of submodels: the driver cost model, the direct vehicle operating cost model, and the long-run cost model. Because driver cost is both the largest cost item and the most variable, it is potentially the largest source of error. It is therefore modeled with the greatest detail. Driver cost estimation is based on the relative efficiency of different driver work assignments. Efficiency is measured by the ratio of pay hours to platform hours (driving hours). The driver cost model requires runcut and schedule data. For a given service contracting package, driver cost is estimated from the number and combination of runs required to operate the service. The model takes the following into account: part-time driver provisions, interlining (the practice of assigning driver runs to more than one route), wage and benefit rates, driver absence coverage (unscheduled pay time), and scheduling practices.

Other direct vehicle operating costs are estimated on a mileage basis using data from Section 15 of the Urban Mass Transportation Act. The long-run administrative and other avoidable costs are also estimated using the appropriate functional categories from Section 15 data. It is assumed that variable long-run costs (maintenance, administrative, and other costs) are directly proportional to output. Admittedly, this is a strong assumption; however, data are not available on the long-run response to major transit service reductions, and cross-sectional data indicate that both maintenance and administrative costs are strongly correlated (approximately 0.91 and 0.97, respectively) to system output, as measured by revenue vehicle miles. A flow diagram of the transit cost model is shown in Figure 1.

The transit cost model was developed primarily for larger transit systems (e.g., with 150 or more vehicles). For smaller systems, data availability is more limited, and the model is simplified accordingly (see section entitled Model Application Results).

The transit cost model also employs alternative assumptions for cost elements that may have an uncertain impact. For example, agencies with part-time drivers may choose to allow the full-time and part-time forces to decline at the same rate, or part-time drivers may be retained while the full-time driver force is allowed to decrease. In addition, maintenance labor costs may not decline immediately in direct proportion to the amount of service contracted in the short run; therefore, a lower bound of a 50 percent proportional reduction in this cost element is assumed. The alternative assumptions are used to generate upper and lower bounds of avoidable cost. These are termed optimistic and pessimistic. A most-probable estimate gives the most likely point estimate of avoidable cost. Alternative assumptions are summarized in Table 1.

Estimating Private Provider Costs

Private operator costs are estimated in a much simpler manner. The private operator cost estimates are used only for illustrative purposes. Actually, private costs would be determined by bids on the service package. For peak period service operated by transit agencies with more than 150 vehicles, private operator costs are estimated with a three-variable cost model based on vehicles, platform hours, and total vehicle mileage. The cost model estimates for peak service generally range between $2.75 and $4.00 per revenue vehicle mile, depending on service characteristics. A flat mileage rate is used for all-day service. The flat mileage rate is adjusted by the size of the transit system and is based on actual survey data for contracted operations of various sizes. The size of the transit system is used as an approximate surrogate for cost differences between private operators of different sizes because the absolute quantity of service that could be contracted is a function of transit system size. It is assumed that service parameters are the same for the private operator. That is, the cost estimate is based on the same platform hours and mileage as that of the transit agency. Because the transit agency owns the vehicles, no capital costs are included.

No distinction is made between short-run and long-run costs for the private operator. Because the service is new, it is assumed that the private operator must incur full service cost at the outset. Alternative assumptions are employed regarding driver pay provisions and direct vehicle operating costs. As with the transit cost model, upper- (pessimistic) and lower- (optimistic) bound estimates are generated from alternative assumptions. Private operator cost parameters are summarized in Table 2. Contract monitoring costs incurred by the transit agency are also included in the private operator cost estimate,

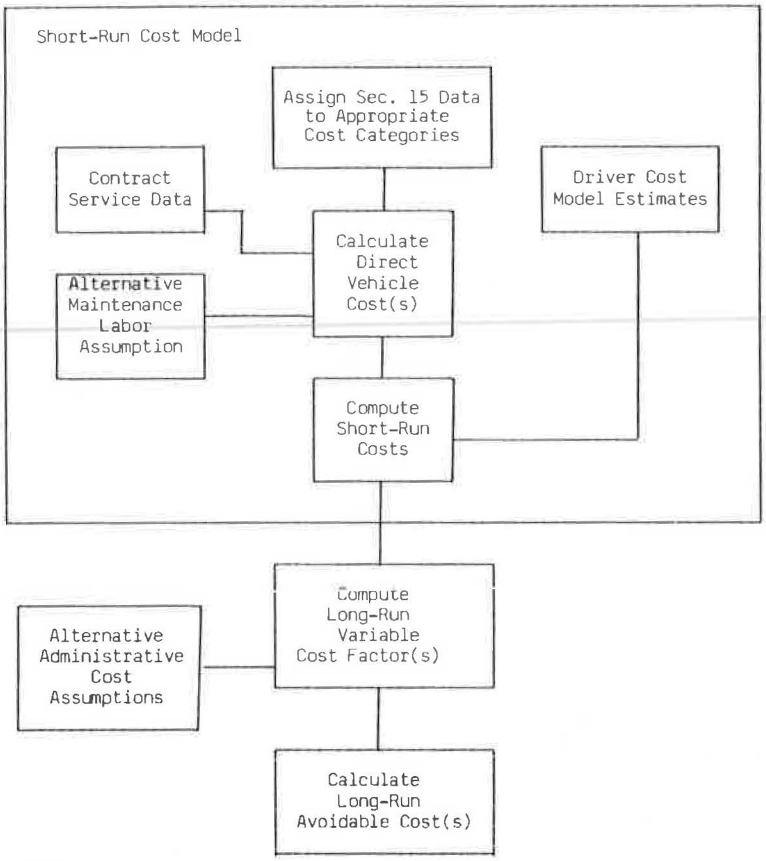

FIGURE 1 Flow chart of the short- and long-range transit cost model.

TABLE 1 ASSUMPTIONS USED TO GENERATE ALTERNATIVE AVOIDABLE COST ESTIMATES FOR TRANSIT AGENCIES WITH MORE THAN 150 VEHICLES

	Optimistic: High Avoidable Cost	Pessimistic: Low Avoidable Cost	Most Probable Avoidable Cost
Driver Cost (Short-Run and Long Run)			
Interlining	Assume all leftover pieces can be reincorporated in schedule with no loss of efficiency	Assume one-third of the leftover pieces must be operated as trippers	Leftover pieces can be reincorporated in service schedule
Part-time operators (PTOs)	Reduce only full-time operators (FTOs) through attrition; retain current number of PTOs	Reduce both FTOs and PTOs through attrition in proportion to current levels of utilization	Reduce both FTOs and PTOs through attrition in proportion to use on contracted service
Direct Vehicle Operating Cost			
Short run only	Maintenance labor cost reduced in same proportion as amount of contracted service	Maintenance labor cost reduced at 50 percent of proportion of amount of contracted service	Maintenance labor cost reduced at 75 percent of proportion of amount of contracted service
Long run	Costs are reduced in the same proportion as amount of contracted service		
Administrative Cost			
Short run	No reduction of administrative costs		
Long run	Proportional reduction in cost of selected administrative functions	No reduction in cost of selected administrative functions	Proportional reduction in cost of selected administrative functions

TABLE 2 PRIVATE CONTRACTOR COST ASSUMPTIONS

	Optimistic (Low Cost)	Pessimistic (High Cost)	Most Probable
Peak-Service Model			
Driver cost	Paid for platform hours only	4-hr guarantee per piece	2-hr guarantee per piece
Mileage-related cost	\$0.72/TVM[a]	\$0.87/TVM	\$0.82/TVM
Administration/overhead	\$10,000/bus/yr	\$10,000/bus/yr	\$10,000/bus/yr
Profit (%)	10	10	10
All-Day Service[b]			
Less than 25 vehicles	\$1.88/RVM[c]	\$1.88/RVM	\$1.88/RVM
25 to 150 vehicles	\$2.00/RVM	\$2.35/RVM	\$2.20/RVM
Greater than 150 vehicles	\$2.00/RVM	\$2.75/RVM	\$2.35/RVM

[a] TVM = total vehicle mile.
[b] All-day service according to transit agency size.
[c] RVM = revenue vehicle mile.

and are adjusted by transit agency size as well. Alternative assumptions are also employed (Table 3).

MODEL APPLICATION RESULTS

The previously described models were used to conduct case studies of 22 U.S. transit agencies. These agencies range from very small (less than 25 vehicles) to very large (1,000 vehicles) and are representative of a wide range of operating conditions and regional differences.

Selection of Service Packages

The case studies were divided into three size categories: small (less than 25 vehicles), medium (25 to 149 vehicles), and large (150 or more vehicles). The 150-vehicle cutoff was used primarily because of size-related cost differences among private operators revealed in the survey data (*4*). In addition, there are size-related differences among public transit agencies. Agencies of less than 150 vehicles, on average, provide very little peak-only service, and therefore have a potentially more efficient service schedule. In addition, several of the case study agencies within this size category report Section 15 data at the less detailed R level, necessitating some adjustments of the transit avoidable cost model.

For the smallest systems, it was reasoned that service contracting would be an all-or-nothing decision because there would be no incentive to incur the burden of monitoring a contractor and continue to operate a minimal amount of service. In addition, it would be very difficult to remove a significant portion of service without adverse effects on the remaining schedule. Thus, for the smallest systems, it was assumed that the whole system would be contracted.

For each transit agency with more than 25 vehicles, at least two service packages were identified, comprising 5 percent and 20 percent, respectively, of the agency's existing service. The 5 percent package corresponds to the first year of contracting, and the 20 percent package represents the maximum possible for a 5-year time horizon given the assumptions presented previously.

The service packages selected consisted of fixed-route service only; no demand-responsive operations or other special services were included. The route selection procedure was to (*a*) calculate the pay hour/platform hour ratio for each route, and (*b*) choose the routes with the highest ratios. The "pay/plat ratio" is the ratio of scheduled pay hours to platform hours (driving hours) for the weekday schedule. It is a measure of schedule efficiency and depends on both the service profile

TABLE 3 TRANSIT AGENCY MONITORING COST ALTERNATIVE ASSUMPTIONS

Transit Agency Size	Pessimistic	Optimistic	Most Probable
Less than 25 vehicles	5% of contract cost; \$30,000 minimum	10% of contract cost; \$75,000 minimum	7.5% of contract cost; \$50,000 minimum
25 to 150 vehicles	5% of contract cost; \$50,000 minimum	10% of contract cost; \$100,000 minimum	7.5% of contract cost; \$75,000 minimum
Greater than 150 vehicles	5% of contract cost; \$75,000 minimum and \$300,000 maximum	10% of contract cost; \$100,000 minimum and \$1,000,000 maximum	7.5% of contract cost; \$100,000 minimum and \$500,000 maximum

TABLE 4 CHARACTERISTICS OF THREE SMALL SYSTEMS

System	No. Peak Vehicles	Average Cost/RVM ($)	Average Cost/RVH ($)[a]	Driver Wage Rate ($)	Peak/Base
A	12	2.45	37.00	9.48	N/A
B	24	2.24	29.00	8.94	2.5
C	21	2.53	27.80	9.08[b]	1.5

[a] RVH = Revenue vehicle hour.
[b] Part-time operator wage is $4.25.

(e.g., peak/base ratio) and driver work rule constraints. This procedure selected predominantly peak-oriented routes first, as would be expected. For some of the largest agencies, an all-day service package was also selected in order to generate comparisons for both peak and nonpeak service. This was not necessary for the medium and small systems, because peak service was exhausted long before the 20 percent limit was reached.

Small System Results

Three case studies of systems with less than 25 peak vehicles were performed; all are municipal systems located in different regions of the United States. The participating transit agencies are not identified by name because of the sensitivity of this research. Descriptive characteristics are given in Table 4. Average hourly costs of Systems B and C are low, as is typical of small systems. System A is located in a high-cost region and has somewhat less favorable work rules than Systems B or C. System B pays a very low overtime rate, can hire up to 40 percent part-time drivers, and has no 8-hr per day guarantee for extraboard drivers. System C provides a 40-hr per week guarantee for drivers and uses part-time drivers with a wage rate of $4.25 per hour for the extraboard. The differences in average mileage costs are due to differences in average speed.

The cost estimation method was adjusted to reflect the entire system's being contracted out, and the much less detailed Section 15 data provided by the small systems. It was also assumed that vehicle insurance would become the responsibility of the private contractor because the public agency would have no reason to retain insurance if it were no longer an operating entity. Costs are long run only, and account for the fixed monitoring, planning, and administrative responsibilities of the transit agencies. Private operator costs are estimated using the costs and assumptions indicated in Tables 2 and 3, plus an estimate of additional insurance costs. Cost savings are calculated by comparing the transit agency avoidable cost with the private operator cost. If the avoidable cost is greater, cost savings will be positive; if the avoidable cost is smaller, cost savings will be negative, indicating that the transit agency would incur higher total costs as a result of service contracting. All cost estimates were made on the basis of annual costs. Results of these comparisons are given in Table 5. Cost savings are computed as a percent of transit agency avoidable costs. Differences between the optimistic, pessimistic, and most probable estimates are due to the alternative monitoring cost assumptions.

TABLE 5 COST SAVINGS FROM PRIVATE CONTRACTING FOR THREE SMALL SYSTEMS

System	Optimistic[a]	Pessimistic	Most Probable
A	9.9	5.6	7.7
B	6.3	1.8	4.1
C	–4.7	–9.7	–7.2

Note: All figures in percentages.
[a] Optimistic estimates give the difference between the highest transit agency avoidable cost and the lowest private cost. Pessimistic estimates compare the lowest transit agency avoidable cost and the highest private cost. The most probable estimate uses the most probable cost for both transit system and private operator.

Because private operator costs are calculated at a constant rate, estimated cost savings are directly related to transit system costs. System A could realize small but significant savings, while System C would incur higher costs. System B would realize very limited savings from contracting. These results are reasonable, considering the characteristics of these systems. Given the level of efficiency of System C, the difference in private operator cost is not enough to offset the fixed administrative and monitoring costs associated with the contracting option. The opposite is the case for System A.

Medium-Size System Results

A total of six case studies were performed for systems of 25 to 150 vehicles. Descriptive characteristics of the case study systems are given in Table 6. The driver compensation rate includes wages and benefits and is calculated from Section 15 data. The pay/plat ratio is calculated from schedule (runcut) data.

Because the medium-size transit systems are less complex operations than the larger systems for which the costing methodology was developed, and because of the more limited data availability, a simpler method of estimating avoidable cost was used. Simplifying assumptions used are (*a*) interlining impacts are not considered, (*b*) maintenance cost is variable in both the short run and long run, and (*c*) a flat 50 percent of administrative cost is fixed in the long run. As described previously, all private operator costs were calculated on the basis of revenue miles using the cost parameters and assumptions in Tables 2 and 3.

Because only one estimate of transit agency avoidable cost is made, the differences in the optimistic, pessimistic, and most-probable estimates are the result of the alternative private operator cost assumptions. Also, the difference between short-

TABLE 6 CHARACTERISTICS OF MEDIUM-SIZE CASE STUDY SYSTEMS

System	No. Vehicles	$/RVM	$/RVH	Driver Wage + Benefits/hr[a] ($)	Peak/Base Ratio	Pay/Plat Ratio
D	31	2.26	29.26	10.54	1.0	1.060
E	40	3.71	49.51	14.91	1.1	1.130
F	120	2.40	39.29	12.22	1.8	1.054
G	130	3.70	43.02	17.00	1.4	1.110
H	142	2.67	42.14	15.21	2.0	1.073
I	144	3.58	45.02	16.50	1.4	1.178

[a] Full-time drivers only.

TABLE 7 ESTIMATED COST SAVINGS FOR 5 PERCENT SERVICE PACKAGES FOR MEDIUM-SIZE SYSTEMS

	Short Run			Long Run		
System	Optimistic	Pessimistic	Most Probable	Optimistic	Pessimistic	Most Probable
D	–17.0	–44.0	–23.0	–5.2	–29.6	–10.3
E	11.9	–11.2	5.5	24.8	5.0	19.3
F	–9.1	–32.0	–24.5	–4.3	–25.5	–18.4
G	–3.9	–25.0	23.8	14.6	–2.8	3.1
H	32.8	19.2	–17.9	42.6	31.0	34.9
I	24.0	8.0	13.4	29.5	14.5	19.2

Note: All figures in percentages.

run and long-run transit agency avoidable cost is the indirect administrative cost.

The service packages were constructed by selecting routes in rank order of pay/plat ratios. The 5 percent packages include all of the peak-only services provided by the transit agency, but in most cases also contain all-day service. It may be noted that these service packages were chosen only for illustrative purposes; no attempt was made to select packages that might be more reasonable from an organizational perspective.

Short-run and long-run results for the 5 percent service packages are given in Table 7. The short-term results correspond to the first year of implementation, when only the direct transit service cost is assumed avoidable. The long-term results correspond to total adjustment of the transit agency. As before, cost savings are calculated as a percentage of avoidable cost.

The results in Table 7 indicate that for most medium-size agencies, significant cost savings are likely in the long run, but that cost reductions will be much smaller, and possibly nonexistent, in the short run. The much smaller (and potentially negative) short-run savings are attributable to the assumed absence of administrative cost reductions by the transit agency in the first year of implementation, as well as by the different private operator cost assumptions. In the long run, however, when all variable cost elements have been reduced proportionately, four of the six agencies save money by contracting according to the most probable scenario. The two agencies that are not predicted to save money have much lower wage rates and more favorable work rules than the other four systems. An example is the 40-hr per week guarantee rather than 8 hr per day, which effectively eliminates daily guarantee time and overtime. It should be noted that these are long-term annual estimates that do not take into account possible short-term losses.

The 20 percent service package provides a more representative indication of the cost impact of large-scale service contracting on transit agencies because a broader range of services are included and all impacts are long run. It is assumed that this magnitude of contracting could occur only after a number of years. Results for the 20 percent service packages are given in Table 8. As before, cost estimates for these systems are based on the simpler costing approach. The results of the 20 percent analysis indicate substantial cost savings in four of six cases. As with the 5 percent package, the negative results for Systems D and F are reasonable given the low wage rate and apparently efficient scheduling practices these agencies employ. Savings are greatest for Systems G, I, and E. Systems G and I have both the highest driver wages, and the highest and third highest pay/plat ratios. System E has the highest average hourly cost, as well as a comparatively high pay/plat ratio, given its low peak/base ratio. The average savings for the most probable scenario is 13.5 percent for the group, with a range from –16.1 to 31.0 percent. The median saving is somewhat higher at 21.1 percent.

TABLE 8 ESTIMATED LONG-RUN COST SAVINGS FOR 20 PERCENT SERVICE PACKAGES FOR MEDIUM-SIZE SYSTEMS

System	Optimistic	Pessimistic	Most Probable
D	–14.0	–40.0	–16.1
E	35.3	20.3	26.7
F	4.7	–12.0	–4.8
G	37.3	22.8	31.0
H	23.3	5.5	15.6
I	35.0	20.2	28.8
Average	20.3	2.8	13.5

Note: All figures in percentages.

TABLE 9 CHARACTERISTICS OF LARGE-SIZE CASE STUDY SYSTEMS

System	No. Vehicles	$/RVM	$/RVH	Driver Wage + Benefits/hr[a] ($)	Peak/Base Ratio	Pay/Plat Ratio
J	199	3.94	40.00	15.78	2.2	1.202
K	521	3.98	58.41	14.99	2.9	1.213
L	762	3.85	64.00	16.30	2.0	1.150
M	800	4.24	58.49	19.31	2.9	1.211
N	320	4.12	54.84	16.19	2.1	1.095
O	402	5.00	69.30	19.70	1.7	1.130
P	441	3.79	62.40	18.96	1.9	1.120
Q	231	3.05	40.48	15.34	2.3	1.160
R	844	3.76	50.69	18.26	1.9	1.130
S	659	4.50	62.72	14.63	2.3	1.150
T	1029	4.59	70.73	18.86	1.8	1.090
U	275	2.32	39.19	11.28	1.3	1.059
V	246	3.54	44.67	18.15	1.3	1.123

[a] Full-time drivers only.

It may also be noted that 20 percent savings are greater than 5 percent (long-run) savings in every case. This result appears to be counterintuitive, given that routes with the highest pay/plat ratio were chosen first. The difference, however, is due to the assumption of a minimum contract monitoring cost. The contract monitoring cost represents a larger proportion of private operator cost in the 5 percent service package because of the smaller total cost of the service package.

Large System Results

A total of 13 case studies were conducted for systems with more than 150 vehicles. Descriptive statistics for these systems are presented in Table 9. There is a substantial variation in size, average unit costs, driver costs, peak/base ratio, and pay/plat ratio. As a group, these are higher cost agencies with higher pay/plat and peak/base ratios than the medium-size systems. Many of these agencies use part-time drivers, but with one exception, they are limited to a maximum of 15 percent of the number of full-time operators.

The avoidable costs for these systems were calculated using the full cost models described previously, and the full range of alternative assumptions given in Tables 1–3. However, alternative costing assumptions for part-time drivers are used only when they are assigned in significant numbers to the service to be contracted and when their wage (plus benefits) rate is significantly different from the full-time driver rate.

Case study results are given in Table 10 for the 5 percent service package and in Table 11 for the 20 percent service package. In some cases (System L for the 5 percent package and Systems J and M for the 20 percent package), alternative service packages were selected to test the effects of different service configurations on estimated cost savings. For the

TABLE 10 ESTIMATED COST SAVINGS FOR 5 PERCENT SERVICE PACKAGES FOR LARGE-SIZE SYSTEMS

	Short Run			Long Run		
System	Optimistic	Pessimistic	Most Probable	Optimistic	Pessimistic	Most Probable
J	9.0	−58.0	−2.7	23.2	−22.9	14.0
K	20.1	−25.0	N/A	34.6	−1.5	29.5
L (express and regional)	18.7	−48.5	<1	36.5	1.0	25.8
L (express)	15.7	−75.4	−5.7	32.8	−17.3	20.8
M	40.0	−43.0	15.0	49.0	2.0	33.0
N	0	−80.2	N/A	32.7	2.3	25.0
O	27.8	−59.9	N/A	50.6	26.0	44.9
P	11.6	−55.9	N/A	31.0	3.7	21.4
Q	5.1	−56.0	N/A	11.0	−28.8	<1
R	29.5	−10.1	N/A	40.8	11.9	34.2
S	25.3	−21.1	N/A	31.4	7.4	26.1
T	10.0	−46.0	N/A	35.8	13.0	23.7
U	N/A	N/A	N/A	14.5	−19.0	<1
V	17.9	−16.2	N/A	29.5	11.6	20.0
Average[a]				32.0	−6.6	22.9

Note: All figures in percentages.

[a] Average excludes L express and regional.

TABLE 11 ESTIMATED COST SAVINGS FOR 20 PERCENT SERVICE PACKAGES FOR LARGE SYSTEMS

System	Optimistic	Pessimistic	Most Probable
J (express and all day)	27.3	−17.8	16.5
J (all day)	32.5	−9.0	19.2
K	35.5	9.7	27.9
L	37.7	18.5	26.9
M (express)	46.0	16.0	37.0
M (all day)	51.0	29.0	42.0
N	40.6	16.2	34.6
O	54.0	35.2	48.9
P	36.0	15.6	28.6
Q	21.7	4.9	15.4
R	43.4	16.8	35.7
S	36.4	20.3	32.7
T	43.3	23.7	34.7
U	15.2	−15.4	2.3
V	33.1	5.5	21.6
Average[a]	36.1	11.4	27.9

Note: All figures in percentages.

[a]Average excludes J and L all day.

remaining systems, routes were chosen on the basis of the pay/plat ratio. As a result, the 5 percent packages are made up primarily of heavily peaked routes.

As shown in Table 10, short-run savings are extremely variable. Pessimistic results, in which only driver costs and a portion of vehicle operation costs are eliminated and the interlining penalty is applied, are consistently negative. Large losses (up to 80 percent) are estimated in several cases. These results suggest that if only a small portion of the system is contracted, immediate savings may be negative. That is, agency short-run costs could increase. Long-run estimates are more positive. The average for the most-probable estimates is 22.9 percent, and none are negative. Only Systems Q and U show no savings. Three of the pessimistic estimates are negative, and all of the optimistic estimates are positive. The optimistic estimates range from 11 to more than 50 percent, with an average of 32.4 percent.

The long-run 20 percent scenarios indicate that savings will occur as all costs elements respond to contracting (Table 11). Again, these are annual estimates. Among the large systems, estimated long-run cost savings are often very large. For Systems M and O, most-probable savings exceed 40 percent, and 6 of the 13 systems have calculated savings of 30 percent or more. Savings are smallest for the system with the lowest wage rate, System U, which also has extremely favorable work rules (extraboard drivers start at $6.00 per hour with no guarantee).

Average most-probable savings for the 20 percent scenario for this group is 27.9 percent, significantly higher than for the medium-size systems. Estimated savings also cover a wide range, from 2.3 percent to 48.9 percent, implying that cost savings are a function of many factors. It is interesting to note that cost savings from contracting tend to be somewhat greater for the all-day service packages than for the express or peak-only packages. This is largely the result of the procedure used to calculate private costs, with alternative driver pay guarantees and overhead based on the number of vehicles employed. When the peak service consists of short pieces of work, private costs are high. Conversely, all-day service estimates tend to better reflect the difference between private and public wage rates.

Overall Results

The contracting cost savings estimates generated in the model applications span a wide range. Results for the 20 percent most-probable scenario for the 19 systems with more than 25 vehicles are summarized in Figure 2. In cases where more than

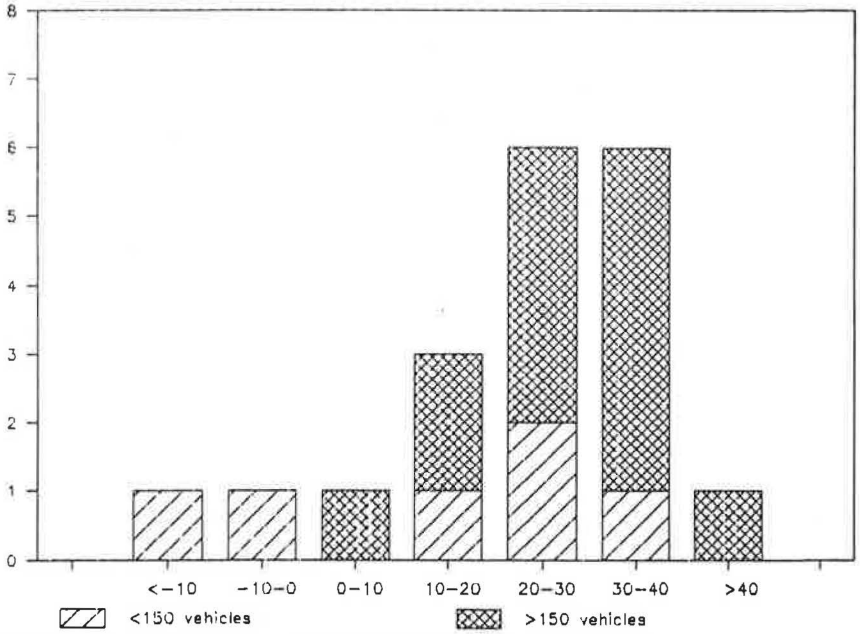

FIGURE 2 Distribution of savings for 20 percent most-probable scenario, all systems with more than 25 vehicles.

one 20 percent scenario was tested, an average value is used. Average most-probable savings is 13.5 percent for the six systems with under 150 vehicles and 27.9 percent for the larger systems. The distributions for the two groups clearly overlap, with the less than 150-vehicle group representing the minimum savings and the more than 150-vehicle group showing the maximum savings. The average savings for the entire sample is 23.4 percent, the median is 27.9 percent, and 12 of the 19 systems fall into the range of 20 to 40 percent.

CONCLUSIONS

The wide range of savings estimated by the model suggests that many factors affect potential cost savings. In part, these differences are a function of the assumptions and parameters used in the models, and the adjustments made to reflect size-related cost differences. It may be recalled that different methodologies were used to generate the cost estimates. For this reason, the case study results should be viewed as having limited comparability between transit agency size categories.

Discussion of Model Results

The wide range of cost savings estimates is also due to transit agency cost and service characteristics. A rough correspondence between transit agency operating costs or driver costs can be observed in the case study results, but the relationship is certainly not consistent enough to be able to use these factors to predict cost savings. Service characteristics, interlining, and the relative proportions of fixed and avoidable costs are important.

Interlining is an important factor in determining transit avoidable costs. The interlining penalty obviously affected the pessimistic avoidable cost estimates, implying that if schedule impacts are significant, potential cost savings will be affected. The impact of interlining is clearly an issue for further research, given the extent and variability of interlining practices within the industry.

The relative proportions of fixed and avoidable costs is another important factor in estimating potential cost savings. The general administration and other functions that are assumed not to change as a result of service contracting make up the fixed portion of long-run costs. The greater the proportion of these costs to total operating cost, the smaller the cost savings, all other things being equal. A high-cost agency may realize only modest cost savings if a large share of operating cost is fixed. Conversely, a lower-cost agency may realize large cost savings if a correspondingly smaller share of operating cost is fixed. In other words, service contracting strategies attack the service-related costs of productivity inefficiencies in public transit, not the nonservice or overhead inefficiencies.

The case study results also indicate that a key factor in transit agency cost savings is the rate at which indirect costs can be reduced. The large differences between short-run and long-run results show that net savings over a 5-year planning horizon are highly dependent on how long it takes to reduce maintenance and other indirect but variable long-run cost items.

Finally, it should be noted that the magnitude of cost savings estimated here would not necessarily hold for contracting larger proportions of transit agency service. Because the most costly service is selected first, the marginal change in cost savings should decline as the quantity contracted increases.

Cost Savings and Transit Costs

It is also interesting to place these estimated cost savings in context. Shown in Figure 3 is a frequency distribution of cost savings as a percentage of operating cost for the 19 systems

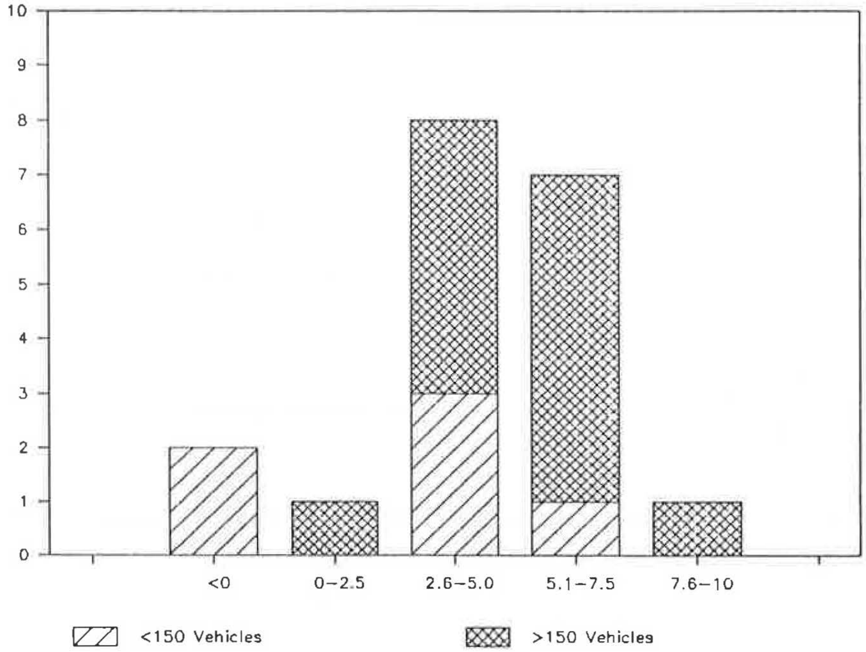

FIGURE 3 Distribution of savings as a percentage of operating cost, all systems with greater than 25 vehicles.

with more than 25 vehicles. The estimate corresponds to the 20 percent most probable scenario. In cases where more than one 20 percent scenario was tested, the peak-oriented service package estimate was used in the frequency distribution. Cost savings as a proportion of operating cost range from –2.5 percent (System D) to 9.0 percent (System O), and the average is 4.2 percent. A total of eight systems have cost savings of more than 5 percent. Savings of this magnitude are significantly greater than the potential savings of more conventional strategies such as using part-time drivers. Of these eight systems, all but one have fleets of 250 vehicles or more. A total of 16 of the 19 systems have estimated savings of 2.5 percent or more, implying that service contracting can generate savings of at least the same magnitude as more conventional strategies for the vast majority of larger U.S. systems.

From the perspective of the transit agency, these results indicate that potential benefits are greatest for the larger agencies, particularly when high wage rates coincide with service characteristics that are relatively favorable to private operator provision. For smaller agencies with low service costs, less controversial cost reduction strategies may be equally effective compared to a relatively low level of service contracting. On the other hand, competitive contracting may create strong cost containment pressures within the transit agency and lead to improved internal cost efficiency—a spillover effect that is not yet evident from other strategies.

From a public policy perspective, these results indicate that efforts to increase private sector contracting should be directed primarily at medium and large transit agencies—those with at least 150 vehicles, and particularly agencies with 250 or more vehicles. Among the transit systems reporting Section 15 data, 13 percent operate fleets of more than 250 buses, yet these 13 percent receive 80 percent of all reported subsidies for bus service. This analysis indicates that agencies of this size average contracting savings of 5.5 percent, and could typically save 5 to 7 percent of their total operating costs by contracting for 20 percent of their service. Nationally, this translates into an annual savings of $260 million to $365 million in required subsidy, or 8 to 11 percent of the nation's total transit subsidy bill for these bus systems. Savings of this magnitude provide a strong economic rationale for increased policy emphasis on competitive procurement of public transit services.

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Urban Transit Profitability by Route and Time of Day

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One of the major initiatives of current federal urban transportation policy is to promote private-sector involvement in planning, operating, and financing urban mass transit services. One means of rapidly expanding private participation in the provision of urban transit service is for the public authorities that now operate almost all transit service in U.S. urban areas to contract with private firms to assume the operation of certain services. Many of the public authorities that now provide these services have objected that such contracting out would "skim the cream" from their systems. By this, they apparently mean that private firms would agree to acquire only those services that earn revenues in excess of their operating costs, thus leaving public authorities with increased deficits and no opportunities to cross-subsidize them from profitable sources. The question of whether the public authorities that currently provide mass transit services in the nation's urban areas are able to operate any of those services profitably is explored in this paper. A major conclusion is that extremely few, if any, urban transit services now operated by public agencies in U.S. cities generate farebox revenues sufficient to cover even their direct, day-to-day operating expenses. Furthermore, farebox coverage of operating expenses appears to be lowest for exactly those services in which both actual and potential private participants have exhibited the greatest interest, so that there appears to be little risk that widespread contracting out of urban transit service will produce increased deficits for any of its current operators.

One of the major initiatives of current federal urban transportation policy is to promote private-sector involvement in planning, operating, and financing urban mass transit services, which have, during the last 2 decades, come to be almost universally owned and managed by government agencies (*1*). During 1965, less than one-half of all transit vehicles were owned by public agencies; but by 1983, such agencies owned 93 percent of the vehicles, provided 95 percent of all service, and carried 95 percent of all transit passengers. The Federal Private Enterprise Participation Policy Statement, issued by UMTA during 1984, states in part that "when developing federally assisted mass transportation plans and programs, UMTA grantees should give timely and fair consideration to the comments on proposals of interested private enterprise entities in order to achieve *maximum feasible private participation*" (emphasis added) (2,p.86). Despite some very recent increases in participation by private transit operators, very little of the conventional transit service in the United States is now operated by private suppliers, either independently or under contract to public transit authorities and regional transportation agencies responsible for providing it.

One means of rapidly expanding private participation in the provision of urban transit service is for the public authorities that now operate almost all of the services to contract with private firms to assume the operation of some of them. The variety of potential candidates for contracting out is wide, but the most logical starting points probably are some fixed-route bus operations, particularly peak-hour express routes and local suburban service, commuter railroad service, and various demand-responsive or paratransit services. Although contracting out has already been extensively employed for demand-responsive service, and commuter rail service is commonly operated by railroad companies under contract to public transit authorities, only about 2 percent of all conventional bus transit service in the United States is currently operated by private firms on a contract basis (2,p.84).

THE CONTROVERSY

Some of the public authorities currently providing urban mass transit services have objected that contracting out would "skim the cream" from their systems. By this, they apparently mean that private firms would agree to acquire only those services that earn revenues in excess of their operating costs, thus leaving public authorities with increased deficits and no opportunities to cross-subsidize them from profitable sources. Representative William Lehman, Chairman of the Transportation Subcommittee of the House Committee on Appropriations, voiced this concern during the subcommittee's May 1985 hearings when he commented that privately operated transit services were desirable only "as long as they do not drain off the best routes from the public transportation [operators] so that public transportation is just left with the more costly to operate types of routes (*3*).

Some advocates of privatization have responded that public transit authorities may be unable to cover the costs of operating any of the services they currently supply, but that private suppliers might be able to operate some routes or types of service at considerably lower costs than the public agencies that currently provide them, thus reducing the subsidy levels necessary to maintain such services. In response to Representative Lehman's concern, for example, one of those testifying before the subcommittee cautioned its members that "public transit authorities lose money on both these ostensible 'cream' passengers and on the others that they carry . . . I think it is a mistake to accept uncritically the argument that by skimming off peak-hour passengers, passengers on express-type services, and others for which higher fares are sometimes charged, that public transit operators would actually see their deficits grow" (*3*).

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Explored in this paper is the question of whether, in the parlance of the industry, there remains any cream to skim. In other words, the ability of public authorities, which currently provide almost all mass transit service in the nation's urban areas, to operate any of those services profitably is investigated. The term "profitable" is defined in the next section. Subsequent sections review the available empirical evidence on the effect of type of service (in terms of route and time period) on transit costs and revenues in order to test whether any transit service currently generates farebox revenues sufficient to meet the definition of profitability.

WHEN IS TRANSIT SERVICE PROFITABLE?

To meet the economist's definition of profitability, a transit service must generate revenues sufficient to cover its expenses for labor, energy, materials, and other operating inputs, as well as to produce some return to its invested capital. Furthermore, for a service to be self-sustaining, this return must suffice to attract new capital at a rate that maintains the total investment necessary to operate it. In urban transit, however, a service is typically said to be profitable if it generates farebox revenues that exceed its direct operating expenses, without any allowance for the depreciation or interest costs for vehicles or fixed-capital facilities dedicated to its provision. A service's direct operating expenses, moreover, are often defined to exclude any allowance for administrative costs or other overhead-type expenses, although at other times expenses include a simple proportional allocation of these cost categories. This situation may occur because there are a number of difficult conceptual problems in allocating expenses that are genuinely common to more than one category of service; however, it may also be a response to the difficulty of taking the actions necessary to reduce these costs when service levels are curtailed.

Although the accounting systems of most public transit operators sometimes make the allocation of farebox revenues among types of service, specific routes, and occasionally even time periods of the day a relatively straightforward process, they generally do not permit ready identification of the costs of operating different categories of service. Judgmental procedures are generally required to allocate the expense categories appearing in transit operators' accounting systems to any desired subdivision of the agency's activities, such as operating divisions, individual routes, or time periods. Thus, not only is the definition of what constitutes profitable service a difficult matter, but the actual measurement of whether individual service categories meet any particular definition is also problematic.

In an effort to minimize these potential difficulties, a very narrow definition of the profitability of individual transit service categories is adopted here. Specifically, the relationship between farebox revenues and direct, day-to-day expenses for various categories of transit service currently operated by a number of different public agencies is investigated. Direct operating expenses are defined to include only labor, energy, and material costs for operating and maintaining vehicles, plus an allowance for investments in and use-related depreciation (as contrasted with depreciation that occurs solely because of the passage of time) of any vehicles that are dedicated to the provision of that service. All expenses for operation and maintenance of fixed facilities (e.g., garages, depots, stations, etc.) and rights-of-way, as well as all expenses for supervisory and administrative functions, are specifically excluded from the definition of direct costs employed here. The major reason for adopting such a conservative definition of costs is to match as closely as possible those expenses that would be instantaneously eliminated by a public agency that successfully contracted with a private supplier to take over a specific service it now operates. Any category of transit service that fails to meet the profitability test under this definition of costs necessarily contributes to increasing the financial deficit of its operator, and its elimination would thus unarguably reduce that deficit.

THE OPERATING RATIO COMPLICATION

Somewhat surprisingly, contracting out or otherwise eliminating a service that now produces a deficit under this definition can actually reduce the fraction of its operator's expenses that is covered by fare revenues, while also raising the deficit per passenger on that operator's remaining services. (A service's farebox receipts expressed as a percentage of its operating expenses are commonly referred to as its operating ratio, although this actually corresponds to the reciprocal of the traditional accounting definition of that term. This measure is also often termed the farebox coverage ratio.) This result has occasionally been used to argue that transferring such services to unsubsidized private providers will leave the public agency that now operates them in worse financial condition than if it continued to operate them and cover a low percentage of their expenses from farebox revenues. Nevertheless, it is important to recognize that the opposite is true.

To see that this is the case, suppose a transit authority operates service on two routes: one offering peak-hour express service at a fare of $1.00 per passenger, and the other offering all-day local service at a fare of 50 cents per rider. Suppose each route costs the authority $1,000 per day to operate, and that each service attracts 600 paying riders each day. Thus, the express service earns total daily revenues of $600, leaving a daily operating deficit of $400, and has a farebox coverage ratio of 60 percent (the $600 in daily fare revenue it generates expressed as a percentage of its $1,000 daily operating expense). Similarly, the local route produces $300 in daily revenue, leaving a daily deficit of $700, and thus generates only 30 percent farebox coverage of operating expenses. In total, the operator of these two routes incurs a daily total deficit of $1,100, or about 92 cents per passenger, and covers 45 percent ($600 plus $300 in daily revenues from the two routes divided by the $2,000 total daily expense for the two routes) of its operating expenses from the farebox.

If the express service were to be assumed by an unsubsidized private operator, some financial statistics for the public agency that continued to operate the local route would indeed appear to be worse: farebox coverage of expenses would decline to the 30 percent figure of the local route, and the deficit per passenger would rise to about $1.17 (the $700 daily deficit incurred in operating the local route divided among the 600 passengers it carries). More important, however, the remaining total deficit would have declined from the initial $1,100 to the $700 figure generated by the local route because the $400 daily deficit on the express route would have been eliminated. In fact, the public agency that formerly operated the express route could subsidize the private operator to which it was transferred or contracted at a rate of up to $399 daily and still reduce its total daily deficit for providing the two types of transit service.

The most visible transit services for which this example is relevant are probably the peak-hour express services currently operated by many public transit agencies, often including commuter railroad service, which is already mainly operated by private railroad companies under contract to public transit agencies. Typically, fares charged for such services are considerably higher than those for regular local bus service, and these premium fares are often sufficient to raise farebox coverage ratios on express service well above their operators' systemwide averages. Nevertheless, these services are often among the most imortant sources of their operators' total deficits simply because their operating costs are so high. For example, one study revealed that express bus routes in Los Angeles covered nearly 40 percent of their operating costs from fare revenues—a figure exceeded at that time only on routes serving central city areas—but still accounted for nearly one-quarter of their operator's total deficit (*4*). Thus contracting the operation of such services to lower-cost private providers might in some cases substantially reduce their current suppliers' total deficits.

TYPES OF TRANSIT SERVICE STUDIED

One useful way to classify transit service is according to the orientation of routes over which vehicles operate and the time period during which service is provided. The service provided by a typical large urban transit authority can be subdivided into various categories using routes and time periods as specified in Table 1. The costs of operating transit services are likely to differ considerably among these different categories, mainly because the productivity with which operators and vehicles can be utilized in each type of service varies widely. Among the most important factors responsible for this are peaking in scheduled service levels during morning and evening commuting hours on some routes, together with provisions of transit operators' labor contracts that restrict the duration of driver work shifts, the use of split shifts, and the hiring of part-time drivers. Other important sources of labor productivity differences among types of transit service are (*a*) varying amounts of nonrevenue service they require (due to vehicle deadheading and layover allowances, for example); (*b*) variation among routes and time periods in the speeds at which transit vehicles can operate in revenue service; and (*c*) differences among passenger trip lengths with route orientation and time periods.

TABLE 1 CLASSIFICATION OF TRANSIT SERVICE TYPES BY TIME PERIOD AND ROUTE LOCATION

	Time Period When Service Operates		
Route Orientation	Weekday Peak	Midday and Night	Weekend and Holiday
CBD[a]-bound radial	XX[b]		
Intown local	XX	XX	
Suburban local		XX	XX
Crosstown or intersuburban			
Rail-system feeder	XX		

[a] Central business district.

[b] XX denotes current participation or apparent interest by private transportation operators in providing this type of service.

In addition, the demand for transit service in most urban areas differs substantially among the types of routes given in Table 1, as well as among the different time periods of the day and week. Some transit operators also impose higher passenger fares for specific services or at certain times of the day, most commonly for radial express routes and during weekday peak hours, while others employ zone surcharges to impose higher fares for longer trips. Together, these factors introduce substantial variation in passenger volumes, average fares actually paid, and the resulting total farebox revenues among the various categories of transit service that are identified in Table 1. In conjunction with variation among these categories in the costs of operating service, these differences in revenue can produce substantial variation in farebox coverage of expenses and operating deficits among individual types of service. If there is any profitability or "cream to skim" within the financial structures of U.S. urban transit systems, it seems most likely to be revealed by an analysis of variation in operating costs and farebox revenues among the categories of transit service identified in Table 1.

EVIDENCE ON VARIATION IN TRANSIT COSTS

A substantial amount of recent research has focused on assessing variation in the costs of supplying transit service of the different types identified in Table 1. This research consists primarily of studies that judgmentally allocate transit agencies' itemized expense accounts to the different services they supply, usually by assigning individual accounts to output measures such as vehicle hours or vehicle miles of transit service (see also *5,6*). This creates estimates of the unit costs for producing each of these outputs, which are then applied to the actual output levels—again, vehicle hours and vehicle miles are the most commonly used of these cost factors—involved in operating a specific service in order to estimate its separate cost. Expenses for management, planning, administration, and other overhead activities are sometimes allocated among individual categories of service, most commonly on the basis of the number of vehicles assigned to each route, time period, or combination of the two, such as the number of vehicles required to operate peak-hour service on each route.

Summarized in Table 2 (*6–12*) are the results of a number of these cost allocation studies that have been documented in recent publications. (Only those studies that describe their results in sufficient detail to allow the examination of cost and revenue variation by individual route, operating division, or service type were used in this research.) As indicated in Table 2, virtually all of the studies report estimates of expenses per vehicle hour and per vehicle mile of service, which were developed by allocating individual operating cost accounts to the output measure with which the authors of the various studies thought they were likely to vary most directly. These unit cost estimates are then applied to the actual numbers of those outputs used to operate different routes or services, which are also reported in Table 2. Finally, each researcher has assigned administrative and other overhead costs to individual routes or services on the basis of some other variable, such as the number of vehicles operated in peak service, also reported in Table 2.

Several adjustments to the various authors' cost estimates reported in Table 2 were necessary to make them useful for investigating the profitability of transit services as defined for the purpose of this study. First, all administrative and other overhead expenditures that are allocated to individual routes or types of service by various researchers are subtracted from their cost estimates because it is unlikely that these expenses would be immediately reduced in exact proportion to any reduction in vehicle requirements or other variables that resulted from a decision to contract out specific services. In fact, it is not clear whether some of these expenses would be reduced at all if the amount of service contracted out represents a small part of the total currently in operation.

Second, the various researchers' estimates of operating expenses per vehicle hour and per vehicle mile were also adjusted downward to eliminate all expenditures other than direct costs for operating the various individual services. As discussed previously, these are defined to include only driver and mechanic labor, energy, and materials expenses for operating and maintaining vehicles. Thus, for example, all expenditures for supervision and administration of vehicle maintenance are excluded wherever they can be determined, as are all expenses associated with operating fixed facilities, such as maintenance garages and vehicle storage areas. Again, the rationale for excluding even these semidirect or variable overhead expenses, as they are often termed, is to produce an estimate of expenses that would vary immediately with changes in service levels. This, in turn, provides an estimate of the minimum cost saving that would immediately and directly result from any decision to reduce service levels, such as to contract out.

A third adjustment is also required in order to render some researchers' estimates of the costs per hour of operating bus transit service a more accurate reflection of the differences in effective wage rates and productivity levels of vehicle operators during peak and off-peak periods. This adjustment, commonly made by transit analysts, raises operating expenses per vehicle hour during peak periods to account for the fact that various pay provisions of drivers' labor contracts, such as minimum guarantees and pay premiums for long or split shifts, raise their effective hourly wage rates during peak periods (*13*). The adjustment also raises estimated peak hourly costs to account for the effect of contractual restrictions on the number and duration of split shifts, which combine with peaking in the demand for transit service to reduce drivers' productivity (the number of hours of passenger-carrying service actually produced per hour for which a driver is paid) during peak periods. The combined effect of these two adjustments is typically to raise estimated expenses per vehicle hour during peak periods by 15 to 20 percent above their overall average value for all time periods (*13*). At the same time, both of these adjustments reduce the estimated costs of operating service during nonpeak periods, most commonly to a level some 10 to 15 percent below their 24-hr average value.

Finally, an allowance for the capital costs of transit vehicles is added to the various researchers' estimates of transit operating expenses. This cost has two separate components, the first of which represents the actual depreciation of transit vehicles with accumulated usage. In contrast to passenger cars, depreciation of transit vehicles appears to be almost exclusively the product of actual use rather than simply of the passage of time, although common industry procedures governing the utilization of buses and the accounting of expenses make it difficult to recognize this (*14*). The estimated allowance for vehicle depreciation, which amounts to about $0.375 per mile over the typical lifetime of conventional transit buses, is added to the estimates of operating expenses per vehicle mile, computed as "straight-line" depreciation of a new bus costing $150,000 over a 400,000-mi useful lifetime. The cost is allocated to vehicle usage in whatever category of service it occurs because it could be reduced in exact proportion to any service reduction by redeploying vehicles to another service, holding them as spares, or selling them to other transit operators.

The other component of capital costs for vehicles represents the interest expense for financing their owners' investments in buses and rail vehicles. At current interest rates (approximately 7 percent after adjusting for anticipated inflation), this cost ranges from $25 to $28 per day for transit buses with typical initial purchase prices of $150,000 and utilization rates of 30,000 to 50,000 mi per year. All of this cost is allocated to peak-period service on the route or service category in question because only by reducing peak-period service levels and vehicle requirements would the number of vehicles purchased (and thus total vehicle financing costs) actually be reduced. Although the costs of vehicle ownership to U.S. urban transit operators are heavily subsidized, particularly by the federal government, most large public transit authorities have bus purchase needs that more than exhaust their available capital subsidies under current allocations. Those that do face the full unsubsidized cost of financing capital investments in the acquisition of additional vehicles, and the savings in these costs that would result from reductions in peak service through contracting out, are thus equal to the unsubsidized interest cost of financing additional bus purchases.

Summarized in Table 3 are the revised estimates of various researchers' reported cost figures that result from applying the various adjustments. Comparing the daily cost estimates for individual services originally reported in Table 2 with the revised values in Table 3 reveals that these adjustments increase some of the authors' reported cost estimates by 5 to 10 percent, primarily because the estimates in Table 3 incorporate some allowance for capital costs, but reduce other researchers' original operating cost estimates to about the same extent. These adjustments also tend to increase the estimated differential between peak and off-peak costs for operating the various services. More important, however, the adjusted costs reported in Table 3 represent more realistic estimates of those expenses that could be immediately eliminated by reducing service, such as those that would result from a decision to contract the operation of some route or entire category of service to a private operator. These revised estimates can then be compared to the farebox revenues generated by the various categories of

TABLE 2 DEVELOPMENT OF OPERATING COST ESTIMATES FOR VARIOUS URBAN TRANSIT SERVICES

					Unit Cost Factors			Daily Operation Inputs Required			
Urban Area	Researcher	Data Year	Type of Service	No. of Routes	$/Vehicle Hours	$/Vehicle Miles	Other	Vehicle Hours	Vehicle Miles	Other	Estimated Daily/ Hourly Operation Cost ($)
Los Angeles	Gephart	1984	Express	1	33.09	0.99	138.73 PO*APB/TB[a]	49.8	1,441	(10+10)(10/10)	5,849/117.45
			Intown	1							
			Peak		30.27	1.14	107.30 PO*APB/TB	37.8	300	(7+9)(8/20)	1,787/47.27
			Off peak		27.10	1.14	107.30 PO*BB/TB	60.5	393	(7)(12/20)	2,538/41.95
			Suburban	1							
			Peak		30.27	1.14	107.30 PO*APB/TB	32.0	472	(5+2)(5.5/9.5)	1,941/60.67
			Off peak		27.10	1.14	107.30 PO*BB/TB	47.6	415	(5+2)(4/9.5)	2,079/43.68
Los Angeles	Wells, Williams	1982	Express								
			Subscription	8	27.90	1.22	109.07/PV-day[b]				4,016
			Park and ride	9	27.90	1.22	109.07/PV-day				34,471
Los Angeles	Cox	1980	Express	?							72,000
			Peak		20.64	0.79	68.92/PV-day				
			Nonpeak		15.86	0.79	68.92/PV-day				
			Intown	?							384,400
			Peak		20.64	0.79	68.92/PV-day				
			Nonpeak		15.86	0.79	68.92/PV-day				
			Suburban	?							147,100
			Peak		20.64	0.79	68.92/PV-day				
			Nonpeak		15.86	0.79	68.92/PV-day				
Orange County	Wells, Williams	1982	Park and ride	5	20.55	0.95	103.60/PV-day				3,702
San Diego	Cervero	1978	Radial	3							
			Peak		23.73	0.43	+3.4% capital[c]	185.0	3,662	31*	6,168/33.34
			Nonpeak		17.50	0.43	+0.6% capital	166.8	3,258	15*	4,346/26.05
			Intown	2							
			Peak		24.75	0.43	+3.4% capital	95.0	889	16*	2,734/28.77
			Nonpeak		17.83	0.43	+0.6% capital	129.5	1,204	12*	2,844/21.96
			Suburban	5							
			Peak		23.67	0.43	+3.4% capital	101.0	1,508	17*	3,142/31.11
			Nonpeak		19.09	0.43	+0.6% capital	176.3	2,655	16*	4,534/25.72

Oakland	Cervero	1979	Express	3							
			Peak only		18.62	0.29	+27.8% OH[d]	275.8	5,861	69*	8,735/31.67
			Radial	4							
			Peak		20.01	0.27	+27.8% OH	484.7	5,846	122*	14,412/29.73
			Nonpeak		17.32	0.27	+2.0% OH	676.8	8,477	50*	14,291/21.16
			Intown	3							
			Peak		19.46	0.27	+27.8% OH	108.9	1,332	28*	3,168/29.09
			Nonpeak		17.43	0.27	+2.0% OH	122.2	1,568	9*	2,604/21.31
			Suburban	5							
			Peak		18.71	0.23	+27.8% OH	242.9	4,965	61*	7,521/30.96
			Nonpeak		18.67	0.24	+2.0% OH	90.2	1,223	7*	2,017/22.36
			Rail feeder	5							
			Peak		18.97	0.28	+27.8% OH	142.5	1,762	36*	4,085/28.67
			Nonpeak		17.97	0.28	+2.0% OH	138.6	1,738	11*	3,037/21.91
San Francisco	Dornan	1980	Commuter rail	1	–	6.81	–	–	8,105	–	55,184
New York	Walder	1981	Peak-only express								
			Yukon	6	27.55	0.60	219.90/PV-day	814.6	15,952	115	50,871/62.45
			Castleton	3	26.82	0.86	189.08/PV-day	187.1	4,051	30	14,174/75.76
			Combined	9	27.41	0.65	213.52/PV-day	1,001.7	20,003	145	65,045/64.93
	Dornan	1980	Commuter rail	?	–	6.87	–	–	162,530	–	1,116,581
Boston	Carey, Campbell	1981	Express	3							
			Peak		30.37	0.86	554.70/PV-day	60.2	761	8*	3,110/51.67
			Nonpeak		27.04	0.86	0	40.3	480	4*	1,222/30.33
			Radial[e]	4							
			Peak		30.37	0.86	554.70/PV-day	147.4	1,356	19*	6,860/46.54
			Nonpeak		27.04	0.86	0	132.1	1,216	12*	3,592/27.19
			Crosstown[f]	7							
			Peak		30.37	0.86	554.70/PV-day	165.8	1,424	21*	8,040/48.49
			Nonpeak		27.04	0.86	0	101.6	873	10*	2,740/26.97
			Suburban	2							
			Peak		30.37	0.86	554.70/PV-day	14.7	217	2*	743/50.52
			Nonpeak		27.04	0.86		5.8	87	1*	189/32.64
	Dornan		Commuter rail	9	–	6.79	–	–	25,875	–	175,691
Washington, D.C.	Dornan	1980	Commuter rail	2	–	9.50	–	–	2,316	–	22,002
Pittsburgh			Commuter rail	2	–	3.93	–	–	2,944	–	11,540
Detroit	Dornan	1980	Commuter rail	1	–	10.22	–	–	830	–	8,482

Note: * = estimated from vehicle hour data assuming (*a*) uniform within-peak service pattern, and (*b*) no nonrevenue service during peaks. OH indicates an added allowance for overhead costs equal to the stated percentage of total vehicle hours plus vehicle mile costs.

[a] PO indicates total daily bus pullouts, defined as the number of buses employed in morning peak service plus the number used to operate evening peak service that were not used for midday service. APB indicates available peak buses, the average of the numbers needed for morning and evening peak period service, and BB indicates base buses, the average number of buses used to provide midday base period service.

[b] PV-day indicates a daily dollar cost allocation per vehicle necessary to operate scheduled peak service on a route.

[c] Factors added to direct operating costs to account for estimated capital charges for vehicles and fixed facilities; thus for example, total operating costs in peak service are estimated to be 103.4 percent of direct operating expenses.

[d] Factors added to direct operating costs to account for estimated general overhead expenses; thus for example, total operating costs in peak service are estimated to be 127.8 percent of direct operating expenses.

[e] Hybrid radial trunk and rail feeder routes.

[f] Circumferential routes; intown travel served by rail system.

TABLE 3 ADJUSTMENT OF VARIOUS RESEARCHERS' OPERATING COST ESTIMATES TO A CONSISTENT BASIS

			Revised Cost Factors[a]			Daily Inputs Assigned			Estimated Study Date Daily Cost
Urban Area	Type of Service	No. of Routes	$/Vehicle Hours	$/Vehicle Miles	$/Vehicle Days	Vehicle Hours	Vehicle Miles	Vehicles	($)
Los Angeles	Peak express	14	31.49	1.08	28.52				72,000
	Intown	Many							384,400
	Peak		28.80	1.19	28.52				
	Nonpeak		25.79	1.19	0				
	Suburban	Many							147,100
	Peak		28.80	1.19	28.52				
	Nonpeak		25.79	1.19	0				
San Diego	Radial	3							12,811
	Peak		21.44	0.77	28.37	185.0	3,662	31	7,666
	Nonpeak		15.81	0.77	0	166.8	3,258	15	5,146
	Intown	2							6,276
	Peak		22.36	0.77	28.37	95.0	889	16	3,263
	Nonpeak		16.11	0.77	0	129.5	1,204	12	3,013
	Suburban	5							8,890
	Peak		21.39	0.77	28.37	101.0	1,508	17	3,804
	Nonpeak		17.25	0.77	0	176.3	2,655	16	5,086
Oakland	Peak express	3	18.62	0.67	27.87	275.8	5,861	69	10,985
	Radial	4							34,131
	Peak		20.01	0.65	27.87	484.7	5,846	122	16,899
	Nonpeak		17.32	0.65	0	676.8	8,477	50	17,232
	Intown	3							6,914
	Peak		19.46	0.65	27.87	108.9	1,332	28	3,765
	Nonpeak		17.43	0.65	0	122.2	1,568	9	3,149
	Suburban	5							11,715
	Peak		18.71	0.61	27.87	242.9	4,965	61	9,273
	Nonpeak		18.67	0.62	0	90.2	1,223	7	2,442
	Rail feeder	5							8,507
	Peak		18.97	0.66	27.87	142.5	1,762	36	4,869
	Nonpeak		17.97	0.66	0	138.6	1,738	11	3,638
San Francisco	Commuter rail	1	–	5.79	–	–	8,105	42[b] 73[c]	46,928
Boston	Express	3							4,655
	Peak		30.37	1.24	24.75	60.2	761	8	2,970
	Nonpeak		27.04	1.24	0	40.3	480	4	1,685
	Radial	4							11,708
	Peak		30.37	1.24	24.75	147.4	1,356	19	6,628
	Nonpeak		27.04	1.24	0	132.1	1,216	12	5,080
	Crosstown	7							11,151
	Peak		30.37	1.24	24.75	165.8	1,424	21	7,321
	Nonpeak		27.04	1.24	0	101.6	873	10	3,830
	Suburban	2							1,030
	Peak		30.37	1.24	24.75	14.7	217	2	765
	Nonpeak		27.04	1.24	0	5.8	87	1	265
	Commuter rail	9	–	6.79	–	–	25,875	37[b] 177[c]	132,739
New York	Peak express	9	27.41	1.03	25.81	1,001.7	2,003	145	51,858
	Yukon	6	27.55	0.98	25.81	814.6	15,952	115	41,043
	Castleton	3	26.82	1.24	25.81	187.1	4,051	30	10,815
	Commuter rail	Many	–	6.87	–	–	162,530	67[b] 250[c] 764[d]	785,020
Washington, D.C.	Commuter rail	2	–	9.50	–	–	2,316	5[b] 32[c]	20,057
Pittsburgh	Commuter rail	2	–	3.62	–	–	2,664	4[b] 15[c]	10,657
Detroit	Commuter rail	1	–	10.22	–	–	830	5[b] 23[c]	7,528

[a] Author's reported unit cost factors are adjusted downward to eliminate any fixed overheads included in reported estimates. Use-related vehicle depreciation is allocated to vehicle miles; interest costs are included in vehicle day unit cost and allocated entirely to peak service.

[b] Local.

[c] Coach.

[d] Spare car.

service in order to assess whether any of them meet the test of profitability proposed here.

FAREBOX REVENUES BY TYPE OF TRANSIT SERVICE

Variation in farebox revenues among transit services stems from two basic sources: (*a*) variation in the demand for different types of service, which determines the number of riders that will use each type at any given fare level; and (*b*) differences in fares charged among individual routes or types of service. Demand variation largely reflects the geographic distributions of residences, employment, and other urban land uses that, together with normal time patterns in social and economic activities, produce substantial variation in urban travel patterns by location, direction, and time of day. In addition, many U.S. urban transit operators charge fares that vary by type of service, time of the day, or length of trip, although these differences are usually quite modest. During 1981, only 9 percent of U.S. transit systems charged higher fares during peak level hours (with an average differential between peak and off-peak fares of approximately 27 percent), while 37 percent of transit operators imposed higher fares for longer trips, and 38 percent charged higher fares for premium services such as express routes (*15*). [Two prominent exceptions to the pattern are commuter railroad service in various urban areas and peak express bus service in New York City, for which sharply higher fares (from $1.00 to $3.10) are charged.]

The combined effect of differences in the demand for transit service by time of day, geographic orientation or route, and variation in fare levels produces substantial differences in ridership and total revenues among different types of urban transit service. Given in Table 4 (*6–12*) are the estimates of average daily ridership, average fare revenue per passenger, and average daily total fare revenue generated by each of the transit services for which operating cost estimates were given in Tables 2 and 3. As the figures in Table 4 indicate, there is considerable variation in farebox revenue among different types of transit routes or services and time periods of the day, even within individual transit systems. Also, as indicated in Table 4, most of this variation is introduced by differences in the demand for different types of service, as reflected in the wide variation in ridership levels among route types and time periods, rather than by variation in fares charged for different types of service.

Part of the variation in average fare revenue per passenger among types of urban bus routes may also reflect different levels of travel on specific routes by passengers who are entitled to fare discounts under their operators' fare policies. Some of these fare discounts are required as conditions for receiving federal transit operating assistance (notably half-fare discounts to elderly and handicapped passengers riding during off-peak periods), and the revenue estimates given in Table 4

TABLE 4 DEVELOPMENT OF FAREBOX REVENUE ESTIMATES FOR VARIOUS URBAN TRANSIT SERVICES

Urban Area	Researcher	Year	Type of Service	No. of Routes	Average Daily Ridership	Average Fare/Rider ($)	Average Daily Fare Revenue ($)
Los Angeles	Cox	1984	Peak express	14	41,500	0.549	22,800
			Intown	Many	881,600	0.158	139,200
			Suburban	Many	136,600	0.276	37,700
San Diego	Cervero	1979	Radial	3	9,862	0.345	3,403
			Peak		8,101	0.355	2,876
			Nonpeak		1,761	0.299	527
			Intown	2	11,226	0.345	3,873
			Suburban	5	5,315	0.345	1,834
SF Bay Area	Cervero	1979	Peak express	3	4,641	0.339	1,573
			Radial	4	52,663	0.289	15,220
			Intown	3	3,573	0.289	1,033
			Suburban	5	3,296	0.289	953
			Rail feeder	5	7,617	0.289	2,201
	Dornan	1980	Commuter rail	1	20,376	1.204	24,553
Boston	Carey, Campbell	1981	Express	3	3,519	0.537	1,890
			Peak		2,708	0.537	1,454
			Nonpeak		811	0.537	436
			Other radial	4	14,962	0.396	5,925
			Crosstown	7	12,446	0.396	4,929
			Suburban	2	670	0.509	341
	Dornan	1980	Commuter rail	9	37,356	1.237	46,215
New York	Walder	1981	Peak express	9	19,856	2.50	49,665
			Yukon Depot	6	15,150	2.50	37,874
			Castleton	3	4,716	2.50	11,791
	Dornan	1980	Commuter rail	Many	269,473	1.84	496,167
Washington, D.C.	Dornan	1980	Commuter rail	2	3,292	3.10	10,198
Pittsburgh	Dornan			2	1,868	1.03	1,929
Detroit	Dornan	1980	Commuter rail	1	2,070	1.00	2,070

should ideally be adjusted to compensate for any revenue loss that results from federally mandated fare reductions. Nevertheless, most of the variation in revenue per passenger within individual transit systems probably reflects the effects of the various fare discounts that a system voluntarily chooses to offer, rather than the effects of discounts it is required to provide. The most important of these are the substantial effective discounts most U.S. transit systems now offer to their regular riders—particularly to regular peak-hour commuters who are the most costly passengers to serve—in the form of weekly or monthly unlimited use passes that are typically priced well below the equivalent of one round trip per weekday. Substantial fare discounts for students, youth, and various other groups are also commonplace. For example, in St. Louis about 13 percent of riders are elderly, and over 20 percent are eligible for youth or student fares; in Philadelphia, elderly and student passengers represent 7 and 12 percent of total ridership, respectively. In cities such as Los Angeles and Seattle, these percentages are approximately reversed (*16*), but the total fraction of riders eligible for reduced fares is still almost 20 percent. Although some of these discounts serve laudable social purposes, others, particularly the discounting of weekly or monthly commuter passes, are not necessarily desirable from a social viewpoint, and entail substantial revenue losses to the large number of transit authorities that currently offer them.

ASSESSING THE "PROFITABILITY" OF TRANSIT SERVICES

Combined in Table 5 are the adjusted estimates of daily direct operating expenses for different types of service operated by various U.S. transit authorities, previously reported in Table 3, with the daily farebox revenue estimates from Table 4. This produces estimates of the average daily deficit that is directly attributable to each of 26 specific categories of service operated by transit authorities in eight of the nation's major urban areas. Also given in Table 5 is the equivalent deficit per passenger for each category of transit service, as well as the percentage of the services direct operating costs, which is covered by the passenger fare revenues generated.

The most striking finding from Table 5 is that none of the categories of transit service reviewed in this study produces farebox revenues sufficient to cover even the direct, day-to-day operating expenses incurred by the public authority that currently provides it. Most services cover far less than half of their direct expenses, as the right-hand column of the table indicates, thus producing per-passenger deficits that are most commonly within the $0.50 to $2.00 range, and reaching nearly $3.00 in several instances. The implication of these figures is unmistakable: even under the narrow, extremely conservative definition of transit costs employed in this study, there are apparently few if any examples of profitable service operated by the public authorities that now provide most U.S. urban transit services. Clearly, there is very little or no "cream to skim" from current public transit operations.

As reported in Table 5, commuter railroad and peak-period express bus service in New York City apparently come the closest to covering their direct operating expenses, but only at quite high average fares ($1.84 and $2.50, as reported in Table 4), and only under definitions of operating expenses that exclude large overhead outlays that are almost completely dedicated to the provision of these services. Aside from these two examples, only a handful of other services generate fare

TABLE 5 DEFICIT ESTIMATES FOR VARIOUS URBAN TRANSIT SERVICES

			Estimated Average Daily ($)				
Urban Area	Type of Service	No. of Routes	Cost	Revenue	Deficit	Deficit/ Passenger ($)	Revenue as Percentage of Cost
Los Angeles	Peak express	14	61,900	22,800	39,100	0.94	36.8
	Intown	Many	330,600	191,400	139,200	0.16	57.9
	Suburban	Many	126,500	37,700	88,800	0.65	29.8
San Diego	Radial	3	12,811	3,403	9,408	0.95	26.6
	Peak		7,666	2,867	4,799	0.59	37.4
	Nonpeak		5,146	527	4,619	2.62	10.2
	Intown	2	6,276	3,873	2,403	0.21	61.7
	Suburban	5	8,890	1,834	7,056	1.33	20.6
San Francisco-Oakland	Peak express	3	10,985	1,573	9,412	2.03	14.3
	Radial	4	34,131	15,220	18,911	0.36	44.6
	Intown	3	6,914	1,033	5,881	1.65	14.9
	Suburban	5	11,715	953	10,762	3.27	8.1
	Rail feeder	5	8,507	2,201	6,306	1.91	25.9
	Commuter rail	1	46,928	24,533	22,395	1.10	52.3
Boston	Express	3	4,655	1,890	2,765	0.79	40.6
	Peak		2,970	1,454	1,516	0.56	49.0
	Nonpeak		1,685	436	1,249	1.54	25.9
	Radial	4	11,708	5,925	5,783	0.39	50.6
	Crosstown	7	11,151	4,929	6,222	0.50	44.2
	Suburban	2	1,030	341	689	1.03	33.1
	Commuter rail	9	132,739	46,215	86,542	2.32	34.8
New York	Peak express	9	51,858	49,665	2,193	0.11	95.8
	Commuter rail	Many	785,020	496,167	288,853	1.07	63.2
Washington, D.C.	Commuter rail	2	20,057	10,198	9,859	2.99	50.8
Pittsburgh	Commuter rail	2	10,657	1,929	8,728	4.67	18.1
Detroit	Commuter rail	1	7,528	2,070	5,456	2.64	27.5

Source: Computed from data reported in Tables 3 and 4.

revenues that cover even one-half of their narrowly defined operating expenses. As indicated in Table 5, farebox coverage ratios for the remaining services are about evenly distributed over the range from 10 to 50 percent, while per-passenger deficits are scattered widely over the range from about $0.20 up to nearly $3.00. (Because costs per passenger carried differ substantially among the categories of transit service studied, there is not necessarily a connection between the farebox coverage ratio and deficit per passenger for an individual service type, although a general relationship between the two is shown in Table 5.)

DIFFERENCES IN FAREBOX COVERAGE BY SERVICE TYPE

In Table 6 the typology of transit service given in Table 1 is combined with the estimates of farebox coverage of operating expenses reported in Table 5, in order to summarize variation in expense coverage by type of transit service. For each combination of transit route orientation and time period during which service operates, the range of farebox coverage ratios developed from the cost and revenue estimates constructed in this study, as reported in Table 5, are given (Table 6). Although almost every category of service for which multiple estimates are available shows a fairly wide range of variation in farebox coverage of expenses, the distribution of estimates within specific categories suggests some interesting patterns.

TABLE 6 FAREBOX REVENUE AS A PERCENTAGE OF DIRECT EXPENSES FOR VARIOUS TYPES OF URBAN TRANSIT SERVICE

	Time Period During Service Operation (%)		
Route Orientation	Weekday Peak	Other Hours[a]	All Hours
CBD-bound radial			
Express bus	14–96	26	41
Local bus	37	10	27–51
Commuter rail	18–51		35–63
Intown local			15–62
Suburban local			8–33
Crosstown or intersuburban			44
Rail-system feeder			26

Note: Direct operating and maintenance expenses plus use-related vehicle depreciation only. Includes no allowance for fixed facilities, managerial personnel, or administrative functions.

[a] Including weekday midday, night, weekend, and holiday service.

Source: Table 4 with figures rounded to nearest whole percent.

The most significant of these patterns shows that farebox coverage generally tends to be lowest for peak-period express, suburban local, and rail-station feeder services (some routes serve a combination of these last two functions), although farebox coverage tends to be highest for intown and crosstown local bus routes. Normal variation in the costs incurred in operating the different types of transit service reinforces this pattern of farebox coverage, thus producing the largest deficits per rider on peak express and suburban local service, and the smallest deficits per rider on intown services, with deficits on crosstown bus routes often falling in between.

Similar to the finding that there are apparently no profitable services currently operated by public transit authorities, the pattern of variation in farebox coverage ratios and deficits per passenger has an extremely important implication for federal policies aimed at promoting private participation in urban transit. The deficits now incurred by public transit authorities appear to be largest for exactly those types of service that private transportation suppliers have shown the most interest in assuming on a for-profit basis or in providing under contract to their current operators. This includes (*a*) peak-period express bus services, which charter and intercity bus operators already handle, both for profit and under contract to public agencies, in many of the nation's larger urban areas; (*b*) suburban local service, which is successfully provided on a demand-responsive basis by taxi companies and passenger van operators in some urban areas; and (*c*) rail-station feeder service, now provided in a few cities with large rapid transit systems by profit-seeking private passenger van owners who operate in spite of local regulatory restrictions.

SUMMARY

The research reported here demonstrates that there are apparently extremely few, if any, urban transit services now operated by public agencies in U.S. cities that generate farebox revenues sufficient to cover even their direct, day-to-day operating expenses. Most types of service provided by large public transit authorities now generate farebox revenues that cover less than one-half of their direct operating expenses, thus producing per-passenger deficits ranging from 50 cents to $3.00. Hence even under the extremely conservative definition of directly attributable costs used in this study, there seems to be very little, if any, "cream to skim" from current public transit operations.

More importantly, farebox coverage of operating expenses appears to be lowest (and deficits per passenger highest) for exactly those services in which private participants have exhibited the greatest interest. Thus there appears to be little risk that widespread contracting out of urban transit service will produce increased deficits for its current operators. Moreover, deficits appear to be largest exactly where the opportunities to reduce them through contracting out or other arrangements involving increased private participation are greatest.

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On-Time Performance and the Exponential Probability Distribution

WAYNE K. TALLEY AND A. JEFF BECKER

In spite of the seemingly strong support for research in on-time performance of bus service, previous research has largely been informal with little statistical basis. In this paper, it is concluded that the distribution of late and early time intervals between actual and scheduled time arrivals for buses at bus stops on a particular route conforms to the exponential probability distribution. The probability equation of the distribution can be used to compute the probability or percentage of buses arriving at a given bus stop that will be more than *x* minutes early or more than *y* minutes late. These probabilities may be interpreted as failure rates. The probability equation allows flexibility in interpreting results and setting standards for on-time performance.

The significant amounts of government funding being provided to public transit firms has given rise to concern regarding public return from such funding. This has led to an interest in studying the performance of public transit firms. Because bus service is the most common to be provided by public transit firms, particular attention has been given to studying its performance.

One area in the performance evaluation of bus service that has received a great deal of attention is on-time performance. On-time performance of bus service has been defined by John Bates (*1*) as "a motorbus passing or leaving a predetermined point along its routing within a time envelope that is no more than *x* minutes earlier and no more than *y* minutes later than a published schedule time." Recently, a survey (*1*) was conducted to determine basic practices and attitudes concerning on-time performance of bus service. The general conclusions of the survey are:

1. There is wide variation in the definition of on-time performance; however, a definition of no more than 1 min early and no more than 5 min late is the most commonly used.
2. Determination of on-time performance appears to be a largely informal practice with little statistical basis.

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3. On-time performance is considered to be an important bus performance characteristic.
4. There is strong support for research in on-time performance of bus service.

The purpose of this paper is to provide a statistical basis for analyzing on-time performance. Specifically, the paper proposes that the exponential probability distribution be used to compute the probabilities that buses (or percentage of buses) on a particular route and arriving at a particular bus stop will be more than x minutes early and more than y minutes late. This approach to evaluating on-time performance of bus service differs from the traditional approach in two major ways: (*a*) the former focuses on those bus arrivals that lie outside of the on-time performance interval as previously discussed, while the latter focuses on those arrivals that lie inside of the on-time performance interval; and (*b*) instead of the traditional approach in providing a formal definition of on-time performance, which a bus stop on a particular route must adhere to, the proposed approach provides probabilities, which buses at a bus stop on a particular route will be more than x minutes early and more than y minutes late; this information, in turn, may be used by transit management for obtaining different definitions of on-time performance depending on the bus stop (and thus route) in question or for evaluating the performance of a route with respect to the stated formal definition of on-time performance.

The methodology based on the exponential probability distribution for evaluating the on-time performance of bus service is presented followed by a section on the application of the methodology to bus routes of the Tidewater Transportation District Commission (TTDC), a public transit firm.

METHODOLOGY

The exponential probability distribution is a continuous distribution with respect to the variable x, where x is the interval (e.g., time) between events. The arithmetic mean (μ) and variance (σ^2) for the exponential probability distribution are computed as follows:

$$\mu = 1/\alpha \qquad (1)$$

$$\sigma^2 = 1/\alpha^2 \qquad (2)$$

The exponential probability distribution restricts the values of x from being negative. A plot of an exponential probability distribution with a mean of 2 ($\mu = 2$) is shown in Figure 1.

A sample of y was obtained in order to endorse the proposal to use exponential probability distribution for computing the probability that buses on a particular route will be more than y minutes late at a bus stop.

The y values for motorbuses arriving at a bus stop on a particular route of the TTDC for a given day were assumed to be distributed as an exponential probability distribution. Let y represent the time interval in minutes for which a bus is late at the bus stop. This time interval is computed by taking the scheduled time of arrival for a bus at the bus stop from the actual time of arrival. Because the exponential probability distribution restricts the values of the variable from being negative, the sample was restricted to consist of only positive values for the variable y (which is concerned only with lateness). This sample in turn, was used in a Kolmogorov-Smirnov Goodness-of-Fit Test to make inference to the null hypothesis that this sample was taken from an exponential probability distribution. This test is described by Sidney Siegel (*2*).

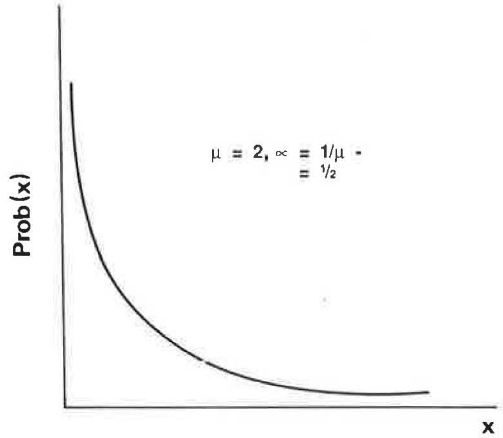

FIGURE 1 Exponential probability distribution.

Based on a 5 percent level of significance, the null hypothesis could not be rejected. This test was also performed with several other samples with respect to lateness and had the same result. Hence, the sample evidence supports the assumption that late time intervals for motorbuses arriving at a bus stop on a given route are distributed as the exponential probability distribution.

In order to provide support for whether the exponential probability distribution can be used for computing the probability that buses on a given route will be more than x minutes early at a particular bus stop, the same analysis was conducted for lateness. Based on a 5 percent level of significance, the null hypothesis could not be rejected. It was concluded that the sample evidence supports the assumption that the distribution of early time intervals for buses arriving at a bus stop on a particular route is determined by exponential probability.

The samples of time intervals for buses have been divided into two sorts: a sample for lateness and a sample for earliness. On-time buses are included in both samples. This follows from the definitions of x and y variables, and from the elimination of negative values for the variables in both samples. x is computed by taking the actual time of arrival from the scheduled time of arrival, and y is computed by taking the scheduled time of arrival from the actual time of arrival, therefore, a motorbus that is on time will be in both samples because $x=y=0$.

Instead of including the on-time buses in both samples, it may be that by measuring on-time performance more accurately (in terms of seconds) no on-time buses for the route will be found. In that case, the problem of what to do with the on-time buses is solved. Alternatively, it may be assumed that the on-time performance of the initially classified on-time buses was not measured correctly and, furthermore, that these buses are equally likely to be late or early. Hence, one-half of these buses may be placed on the early bus sample and the other one-half in the late bus sample for the given route. A final alternative is to eliminate those buses that are actually found to be on time (measured in seconds) from either sample for the route.

Based on the preceding discussion, exponential probability distribution can be relied on for computing the probability that daily buses on a particular route will be more than x minutes early or more than y minutes late at a given bus stop. The following discussion concerns late arrivals; however, the same conclusions also pertain to early arrivals.

The probability that buses will be more than b minutes late can be computed from the following formula

$$\text{Prob}\ (y > b) = e^{-ab} \qquad (3)$$

Where, e is the base of natural logarithms, and a equals 1 divided by the arithmetic mean of the values of y in the sample.

Suppose in a sample of daily late arrivals (also including on-time arrivals) that the arithmetic mean of the arrivals was 1.63 min late. If b is specified to be 5 min late (the generally accepted standard at present), then the probability that buses on this route will be more than 5 min late will be 0.0498 or

$$\text{Prob}\ (y > 5) = e^{(-1/1.63)5} = 0.0498 \qquad (4)$$

For the purpose of evaluating the on-time performance of bus service, the exponential probability distribution provides a great deal of flexibility for transit management. For example, there are three unknowns in Equation 3: (*a*) the Prob ($y > b$), (*b*) the parameter a, and (*c*) the parameter b. Given any two of these unknowns, Equation 3 can be used to determine the third. In Equation 4 values for a and b are specified and solved for Prob ($y > b$). Values for Prob ($y > b$) and a can also be specified and solved for b. The final possibility is to specify Prob ($y > b$) and b and solve for a or the reciprocal of the arithmetic mean of the late arrival observations.

TABLE 1 ON-TIME PERFORMANCE FOR LATENESS

Route	No. of Observations > or = 0 Min Late	Average Late Adherence (min)	Probability Bus More Than 5 Min Late (%)	5 Percent Buses May Be This Late (min)	Buses 1 Min Early to 5 Min Late (%)
1	71	2.93	18.2	8.8	78
2	27	1.97	7.9	5.9	90
3	49	2.12	9.5	6.3	87
4	69	2.55	14.1	7.6	84
5	19	1.84	6.6	5.5	96
6	29	7.84	52.8	23.4	77
8	17	4.88	35.9	14.6	78
9	15	2.67	15.4	8.0	88
10	18	1.67	5.0	5.0	100
11	30	2.20	10.3	6.6	85
12	17	3.30	22.0	9.9	74
13	24	3.96	28.3	11.8	68
15	17	0.86	0.3	2.6	92
16	14	2.86	17.4	8.6	88
17	16	2.75	16.2	8.2	89
18	30	4.73	34.7	14.1	69
19	5	1.40	2.8	4.2	100
20	39	3.72	6.1	11.1	52
20X	5	1.60	4.4	4.8	86
22	10	0.60	0.0	1.8	100
23	33	3.22	21.2	9.6	89
26	41	2.02	8.4	6.0	100
35	2	1.50	3.6	4.5	100
36	6	8.00	53.5	23.9	70
37	2	3.50	24.0	10.5	33
39	29	0.90	0.4	2.7	100
40	39	0.79	0.2	2.4	94
41	8	2.00	8.2	6.0	78
44	10	0.60	0.0	1.8	82
45	64	5.47	40.1	16.4	63
46	10	3.60	24.9	10.8	82
47	22	2.27	11.1	6.8	86
49	17	2.25	10.8	6.7	94
50	11	0.73	0.1	2.2	91
71	11	7.18	49.8	21.5	26
72	11	0.57	0.0	1.7	38
73	15	8.14	54.1	24.3	41
74	22	3.37	22.7	10.1	51
75	15	5.67	41.4	17.0	44
76	17	8.24	54.5	24.6	38
80	16	2.19	10.2	6.5	89

APPLICATION OF METHODOLOGY TO THE TTDC

The TTDC is a public transit firm chartered in the Commonwealth of Virginia to plan, operate, and regulate public transportation services. Five cities (Chesapeake, Norfolk, Portsmouth, Suffolk, and Virginia Beach) are members of the TTDC and receive public passenger transportation from the TTDC. The TTDC provides a variety of public passenger transportation services, including bus, dial-a-ride, elderly and handicapped, ferry, and vanpool. With respect to bus service, the TTDC is a medium-sized system with 120 peak-hour buses on 41 routes

Time intervals between scheduled and actual time of arrival for buses arriving at a bus stop on each of the 41 routes were obtained for a typical day. The arithmetic means of the late and early arrivals (where on-time arrivals are included in both types of arrivals) for the 41 routes were computed (see Table 1 and Table 2, respectively).

As stated previously, the most commonly used definition of on-time performance by U.S. bus firms is no more than 1 min early and no more than 5 min late. The rationale for selecting this definition is not clear, but appears to be based on a reasonable waiting time for buses delayed due to travel conditions. Early departure is regarded as unnecessary and undesirable.

The failure rate with respect to the preceding definition of on-time performance may be obtained with the aid of the exponential probability distribution. The failure rates (5 min late) for TTDC's 41 routes are given in the fourth column of Table 1; failure rates (1 min early) for TTDC's 41 routes are found in the fourth column of Table 2. Note that these columns are not additive. With respect to the TTDC's lateness samples, the probability that buses will be more than 5 min late ranges from 0 to 54.5 percent for the routes. With respect to the TTDC's earliness samples, the probability that buses will be more than 1 min early ranges from zero to 81.9 percent for the routes. Given the wide range in the failure rates in being late

TABLE 2 ON-TIME PERFORMANCE FOR EARLINESS

Route	No. of Observations < or = 0 Min Early	Average Early Adherence (min)	Probability Bus More Than 5 Min Early (%)	5 Percent Buses May Be This Early (min)
1	27	0.30	3.6	0.9
2	17	0.29	3.2	0.9
3	24	0.38	7.2	1.1
4	36	0.26	2.1	0.8
5	8	0.75	26.4	2.2
6	10	0.30	3.6	0.9
8	2	1.00	36.8	3.0
9	6	0.33	4.8	1.0
10	7	0.43	9.8	1.3
11	12	0.25	1.8	0.7
12	7	0.29	3.2	0.9
13	6	0.17	0.3	0.5
15	19	0.66	22.0	2.0
16	3	0.67	22.5	2.0
17	5	0.60	18.9	1.8
18	15	2.00	60.7	6.0
19	2	0.50	13.5	1.5
20	31	1.86	58.4	5.6
20X	3	2.00	60.7	6.0
22	4	0.00	0.0	0.0
23	6	0.83	30.0	2.5
26	23	0.13	0.0	0.4
35	0	0.00	0.0	0.0
36	7	1.29	46.1	3.9
37	1	3.00	71.7	9.0
39	17	0.00	0.0	0.0
40	33	0.51	14.1	1.5
41	5	0.20	0.7	0.6
44	7	1.14	41.6	3.4
45	22	0.85	30.8	2.5
46	2	0.50	13.5	1.5
47	14	0.50	13.5	1.5
49	10	0.50	13.5	1.5
50	9	0.00	0.0	0.0
71	14	3.71	76.4	11.1
72	15	2.07	61.7	6.2
73	4	3.60	75.7	10.8
74	25	2.74	69.4	8.2
75	7	1.57	52.9	4.7
76	3	5.00	81.9	15.0
80	10	0.30	3.6	0.9

and early, the question arises as to whether the restrictions of on-time performance as defined (5 min late and 1 min early) are appropriate for every route. A higher value for b (late or early) may be acceptable for a more congestion-prone route.

Instead of focusing on the probability of failure rates, management may want to examine the magnitude of the failure to adhere to a schedule. Suppose transit management initially considers setting the limits for the definition of on-time performance based on a failure rate of 5 percent for being late and early. For the TTDC (see Column 5, Table 1), lateness limits will range from 1.7 min to 24.6 min for the routes; earliness limits (see Column 5, Table 2) will range from 0 to 15 min. If transit management chooses a higher failure rate of 10 percent, the ranges of the limits will become smaller.

Practically speaking, transit management may seek to keep the commonly used definition of on-time performance: no more than 5 min late and no more than 1 min early (see Column 6, Table 1). In that case, management may use the fourth columns in Tables 1 and 2 to determine whether a route is adhering to the definition of on-time performance with respect to certain probability limits. Suppose management states that a given route is adhering to the definition of on-time performance if the failure rate for lateness and earliness does not exceed 10 percent. In Table 1, 25 of the routes exceed this failure rate with respect to lateness; in Table 2, 24 of the routes exceed this failure rate with respect to earliness.

By increasing the acceptable failure rate, the number of routes with failure rates exceeding the acceptable rate will decrease. Hence, transit management might begin by stating a relatively high acceptable failure rate and concentrate on those few routes that exceed this rate by attempting to correct the problems that have caused the routes' relatively high failure rate. Over time the acceptable failure rate could be lowered in order to select those routes that are to be investigated for the purpose of improving their on-time performance. Furthermore, because probabilities are available for lateness and earliness, transit management can detect a route that may have an early on-time performance problem but not a late problem, and vice versa.

CONCLUSIONS

Although there appears to be strong support for research in on-time performance of bus service, previous research has largely been an informal practice with little statistical basis. In this paper, it is concluded that distribution of late and early schedule adherence intervals for buses arriving at a bus stop on a particular route conforms to the exponential probability. If the definition of on-time performance states that a bus at a bus stop will be no more than x minutes early and y minutes late, the probability equation of the exponential probability distribution can be used for computing the failure rate with respect to these limits. Specifically, the probability equation can be used to compute the probability or percentage of buses arriving at a given bus stop that will be more than x minutes early and more than y minutes late. Once transit management specifies the acceptable failure rates for being late and early, the probabilities given here can be compared with rates used for detecting bus routes experiencing problems that cause relatively high failure rates.

A major problem that arises when applying the methodology described is the categorization of samples (early or late) of buses that are initially classified as on time. This problem may be solved by measuring the on-time performance of buses more accurately (in terms of seconds), so that no buses are classified as on time for the route. The appropriate method for handling this problem will be deferred to future research. However, whichever method is selected, researchers should be aware that the proposed methodology serves as a stastistically rigorous screening device for detecting bus routes with possible on-time performance problems rather than as a forecasting model of schedule adherence.

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Assaults on Bus Staff in Great Britain

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The incidence, causes, and methods of ameliorating assaults on bus staff in Great Britain are examined. Over 13,800 assaults were reported in the years 1979 to 1985, with over one-half of these resulting in staff absenteeism. The major causes are disputes over fares, hooliganism, and traffic incidents. Although London has a more severe problem than elsewhere, assaults are not just a phenomenon of large cities: some operators in small towns also have proportionally high levels of assaults. However, recent initiatives by operators and police authorities, including more use of radio communications, on-bus videos, schools, public relations programs, and a greater police presence do appear to be reducing the number of assaults in some areas.

Assaults on bus-operating staff are a serious problem in Great Britain. In 1984 an ad hoc working group was set up under the aegis of the British Department of Transport to examine the problem and possible solutions (*1*). As part of the work to support this the Department of Transport commissioned research into the incidence and causes of assaults on bus staff and on the methods that operators were using to try to ameliorate the problem. The results of that research are presented in this paper.

LEVELS OF ASSAULTS

Over the years 1979–1985, just over 13,800 incidents were reported by bus operators in Great Britain. The incidents fall into three categories:

1. Those resulting in bus staff absenteeism;
2. Those in which staff were physically assaulted but which did not result in any absences; and
3. Other incidents, usually arguments and disputes with no physical contact.

Research in London (*2*) suggests that only two-thirds of actual assaults are reported, therefore 13,800 is probably an underestimate of the true number of incidents.

Assaults should be considered in the context of factors such as the numbers of passengers being carried and the number of bus-operating staff. In Table 1 the average levels of assaults over recent years for 40 undertakings are given with the number of passenger journeys as a common basis of measurement.

The undertakings are divided into four categories: (*a*) Passenger Transport Executives (PTE) that provide services in major conurbations, (*b*) municipal operators that provide services in small- to medium-sized urban areas, and (*c*) National Bus Company (NBC) subsidiaries that operate in a variety of areas that are predominantly rural and small urban areas but also include some larger cities. London Buses Ltd. (LBL) is identified separately.

The incidence of assaults on bus staff is not a big-city phenomenon when measured against passenger journeys. For example some of the PTEs have a much lower relative incidence of assaults than many of the municipal operators running services in much smaller free-standing towns. The NBC subsidiaries generally have less of a problem than either the PTEs or the municipals, and those with a comparable level of assaults include larger urban areas in their operating territory.

As shown in Table 1, reported assaults vary from year to year but have tended to increase in London and among municipal operators. NBC figures peaked in 1983, while PTE assaults reached their highest level in 1985 after a considerable fall in 1984. As the figures show, LBL faces a problem far worse than the other operators.

The figures given in Table 1 relate to all reported incidents. Within the British bus industry there is a view that more serious assaults (those leading to staff absenteeism) are growing rather faster than total incidents. From the perspective of management, this increase is linked to a growing use of weapons, particularly of knives. Disaggregation from the effect of assault tends to support this view. In 1980 assaults causing staff absenteeism amounted to 48 percent of all reported incidents. By 1983 this figure had risen to 60 percent, and although the proportion fell back to 54 percent in 1984, the underlying trend does appear to be upward.

As mentioned, LBL has a much more serious problem than any other operator in Great Britain. Nationally LBL carries about 20 percent of all bus passenger journeys but accounts for over 60 percent of all reported assaults. One feature of LBL's services that distinguishes it from other operators is its still extensive use of bus conductors. Data collected by LBL shows that conductors are almost six times as likely to be the subject of an assault as are drivers. Outside London the difference is less dramatic but is nonetheless still apparent, with conductors about twice as likely to be assaulted as drivers.

CAUSES OF ASSAULTS

Although the underlying reasons for an assault may be the antisocial attitudes of the people involved, the ostensible causes are many and varied. Principal among these are disputes over fares, including attempted fare evasion, arguments over the validity of passes, change (which is still given by the majority of operators), overriding, and disputes about child fares (see Table 2).

Hooliganism and bad behaviour are another major cause of assaults as are traffic incidents. The latter refer to disputes between the bus driver and other road users over such matters as vehicles parked at bus stops, or bus drivers not showing

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TABLE 1 INCIDENCE OF ASSAULTS 1980–1985

Operator Category	Type of Assault	No. Assaults Per 10 Million Passenger Journeys					
		1980	1981	1982	1983	1984	1985
PTE (4)	A	0.901	0.875	0.727	1.066	NA	NA
	B	1.713	2.006	2.092	1.763	NA	NA
	Total	2.614	2.881	2.819	2.829	2.488	3.012
Municipal (17)	A	0.628	0.535	0.659	0.681	0.881	0.638
	B	1.955	1.759	2.196	2.042	2.803	2.533
	Total	2.583	2.294	2.855	2.723	3.684	3.171
NBC (18)	A	0.293	0.319	0.167	0.366	0.379	0.361
	B	0.860	0.779	0.910	0.951	0.813	0.536
	Total	1.153	1.098	1.077	1.317	1.192	0.897
London (LBL)	A	5.435	6.972	6.976	7.837	7.053	7.633
	B	4.057	2.352	4.818	2.768	3.595	4.227
	Total	1.492	9.324	11.794	10.605	10.648	11.860

Notes: Assault Type A causes staff to be absent from duty for 1 day or more, and assault Type B indicates other assaults.
PTE 1985 figure is estimated.
Parenthetical numbers in the Operator Category column represent the number of operators who provided data over the 6 years.
LBL represents a single operator.

normal courtesy to other road users. Traffic accidents are a relatively insignificant cause of assaults.

Disputes arising from passengers trying to board or alight at places other than recognized bus stops also frequently lead to assaults. They are more common in London, where a substantial proportion of the buses have open rear platforms for entrance and exit, than elsewhere where buses have automatic doors controlled by the driver.

Robbery of the crew or passengers is still a relatively rare occurrence, and drunkenness is not as commonly reported as might be expected. However, alcohol probably plays a larger part as a causal factor than figures (Table 2) suggest. If the

TABLE 2 CAUSES OF ASSAULTS: LBL AND OTHER OPERATORS

Cause	LBL (%)	Other Operators (%)
Overriding	4.3	2.4
Child/adult fare dispute	3.1	0.4
Change	2.5	1.0
Pass/fare card	1.6	2.2
Fare evasion/refusal	8.3	3.2
Other ticket disputes	22.5	17.2
Subtotal	42.3	26.4
Drunkenness	3.1	5.2
Verbal abuse	1.2	1.9
Remarks by crew	2.1	0.1
Hooliganism	9.3	12.0
Scheduling/gaps in service	2.5	0.7
Boarding/alighting	7.4	4.3
Seating/standing	3.3	0.5
Traffic incident	6.4	7.4
Traffic accident	1.0	0.9
Accident to passenger	0.2	0.1
Robbery of crew	1.7	2.1
Robbery of passenger	0.4	0.2
Racial attacks	0.1	0.3
Missiles	2.1	5.0
Other causes	12.0	7.4
No apparent reason	2.6	8.9
Reason not reported	2.3	16.6
Subtotal	57.7	73.6
Grand Total	100.0	110.0

occurrence of assaults by time of day is examined there is a distinct peak in the late evening from 10 p.m. Most licensed premises (public houses serving alcoholic beverages) close at 10:30 p.m. or 11 p.m., and it is likely that the sharp increase in reported incidents at this time is connected with passengers who have drunk well but not wisely. There is also a secondary peak in the late afternoon, which is primarily due to incidents involving juveniles on their way home from school.

A diurnal pattern to assaults is detectable with proportionately more occurring on Fridays and Saturdays. These two days account for 34.5 percent of all reported assaults in London, and 41.2 percent elsewhere. Although the figures for Sundays are only approximately 60 percent of the Monday to Thursday level, both service provision and ridership are much lower on Sundays. There is no national data against which to measure the incidence of assaults by daily ridership, but in proportionate terms, the Sunday level may be even higher than Friday and Saturday levels.

COSTS OF ASSAULTS

The effects of assaults in terms of costs can be measured in a number of ways: (*a*) directly, when services are disrupted, (*b*) lost staff time, and (*c*) indirectly, when bus operators have to take measures to deal with assaults. Staff absenteeism due to assaults amounts to over 20,000 person days per annum of which almost 90 percent is attributable to LBL staff. At current value absenteeism costs the industry around £1 million a year.

In addition to the cost of length of absence from duty, costs also arise from service disruptions and resignations. Severe assaults have led to staff resignations. This is not a common occurrence and is becoming less frequent largely because of better arrangements between staff and management over the procedures to be followed after an assault. Nonetheless it does happen and the loss of fare revenue can be significant nationally, running into some tens of thousands of pounds.

The social costs of assaults include the pain and discomfort suffered by the victims; the costs incurred by the National Health Service and other social and welfare agencies, and the expenses involved in tracing, apprehending, and prosecuting assailants. When services are withdrawn there is a cost, over and above the direct fares loss, attributable to the inconvenience to passengers. There may also be a reluctance on the part of the public to use bus services at certain times and in certain areas. For those operators where assaults are a serious problem high turnover of staff may in part arise because of violence, and there is some evidence of increased staff absenteeism when staff report sick in order to avoid duty on a service where there is a greater risk of an assault.

Finally costs are incurred from countermeasures taken by the operators; costs reported by operators for these are incomplete. For example, some operators consider the installation of radio communication systems as a means of combating assaults and regard the costs as a cost of assaults. Other operators do not. An increasing number of operators include some training in interpersonal skills for their operating staff, but the costs of these training programs are not reported. Specific physical measures, such as fitting protective screens over the driver's (interior) cab door or alarm systems, are usually reported, but more general activities, such as publicity campaigns or education programs at schools, are seldom included. Over the period 1979 to 1985 undertakings outside London reported expenditure of just over £9 million of which 93 percent (£8,734,000) was attributable to radio systems. Expenditure on protection screens amounted to just over £250,000, and £100,000 was spent on alarm systems.

POLICE INVOLVEMENT AND PROSECUTION

Outside of London the police were involved (1979–1984) in 80 percent of incidents, usually in the sense of being informed of the occurrence of an assault.

It is unsurprising that, given the short time during which an assault takes place, only 21 percent of the assaults outside London have led to a prosecution. However there is no information available for a further 18 percent, some of which may have resulted in court proceedings.

When records contained information that an assailant had been prosecuted, an analysis of the results showed that the most common outcome was a fine, sometimes with compensation to be paid to the victim. The amount of the fines varied but were seldom large, most were below £100. Custodial sentences were given in 20 percent of cases, but were more commonly given (in 38 percent of cases) when the assault was severe. Sentencing policy for assailants is an issue that causes the industry some concern. Among the staff there is a general feeling that sentences are not severe enough in relation to the crime and as deterrents.

PREVENTIVE MEASURES

A wide range of preventive measures are being adopted by British operators. These include fitting drivers' cabs with protective screens, on-bus radio systems with emergency or panic buttons that can be used to alert control that an assault is in progress, and on-bus video cameras.

Early evidence from London, where all one-person-operated (OPO) buses were fitted with screens in August 1986, shows a 30 percent decrease in assaults on drivers. Other city operators provided with fitted screens have also found a significant decrease in assaults.

Use of radios probably reduces the number of assaults (perhaps by approximately 5 percent), but it is difficult to quantify. Evidence from one city operator in Leicester suggests that the ability to summon police assistance quickly via a radio link does increase the proportion of assailants who are apprehended. Similarly early experience with videos suggests that they act as a deterrent and increase the probability of an assailant's being caught. However, videos are regarded principally as a means of preventing vandalism.

Currently, more attention is being given to training staff in how to defuse a potential assault situation, mainly through training in interactive skills. Studies have shown that such training can change staff attitudes but there is as yet no conclusive evidence that this leads to a reduction in assaults.

Publicity campaigns and reward schemes have been introduced by some operators with some success, but one of the more interesting public initiatives is Cleveland Transit's adopta-bus scheme in Middlesborough, whereby a school adopts a specific bus, is given a photograph of the bus, together with brief vehicle details, and is encouraged to consider the bus as its own. Some misgivings have been expressed that a rival school might regard the other's bus as fair game for vandalism; however, to date this has not happened. It appears that the scheme is successful and 12 months after it started 48 schools in the Cleveland area had adopted a bus. The operator there eventually expects to have about 140 adopted vehicles.

Liaison with the police continues to improve in most areas in Britain. In London, the police introduced a hop-on-a-bus scheme in which all uniformed officers were instructed that, where a bus route crossed their beat, they should board and travel on a bus (free of charge) at least once during their tour of duty. Additional backup was provided in those areas known to suffer most from assaults on bus staff through the deployment of District Support Unit Officers and plain clothes officers. Other operators have used local police, particularly in the late evening, to deal with services where many passengers were refusing to pay fares.

When considering ways to reduce the probability of violence, bus fares and fare policy should not be overlooked. Arguments over fares are the most common cause of assaults (see Table 2). Research shows two specific fare-related causes of assaults. In one case, (Cleveland) an experimental low fare of 10 pence was introduced for distances in and around the central area with the next fare set at 25 or 30 pence. This difference in fares led to overriding and, consequently, a number of incidents. As a result, the fare system was changed to one based on zoning, which subsequently reduced the incidents caused by overriding.

A different aspect of the same problem of a large fare differential was reported in Nottingham where the child fare is less than one-half of the adult fare precipitating arguments over the age of the child, particularly in the late evening. The suggestion under consideration is to revise the fare structure in the late evening to require all passengers, including children, to pay either a full fare or a flat fare. In general, it is believed that increased off-bus ticketing with passes and multiride tickets reduce the number of incidents in most cases.

CONCLUSIONS

As shown by the data collected during the course of this study, assaults on bus staff are a serious problem although they are by no means universal. The number of assaults, particularly serious ones, has increased since the late 1970s; however, most recent data suggest that assaults may now be declining, at least in some areas.

The Department of Transport's Working Group on Violence to Road Passenger Transport produced close to 40 recommendations including those discussed in this paper, as well as provision of improved arrangements within undertakings to handle the aftermath of assaults and improved after-care for victims. Much remains to be done including seeking a clearer understanding of the causes of violence and improving the efficiency of some of the remedies. Further research for the latter is being undertaken in four areas: staff training, police liaison, use of protective shields in cabs, and use of radio communications.

The initial results of the more in-depth studies suggest that progress can be made to reduce the number of assaults, and it seems likely that the methods increasingly being used by operators have substantially helped to reverse the trend toward increased assaults.

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Development of a Bus Operating Cost Allocation Model Compatible with UMTA Urban Transportation Planning System Models

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Traditionally, bus operating cost models have been based on actual bus components or expenditures, and unit coefficients have been assigned to these based on actual or estimated costs. Such models are usually applied as linear models in which the unit coefficients are applied to such measures as vehicle miles and vehicle hours of service. The development of a cost-allocation model is documented here. The model differs from the traditional ones by separating costs into fixed and variable components and by using multiple-step functions that reflect the increments of costs or savings generated through changes in the number of employees required to operate the bus system. The model is based on an extensive analysis of the budget data of a large bus operator (the Southern California Rapid Transit System), and provides an example of how a model can be developed for any size of operation if records are maintained on a reasonably detailed budgeting level. The model was developed to be compatible with the UMTA Transportation Planning System (UTPS) models, and can be used both to assist in evaluating alternative long-range transit networks as well as an effective short-range planning and costing tool. The model is currently developed as a microcomputer model that runs on a database developed from the scheduling data of the system. A series of sensitivity tests that have been applied to the model to determine how it behaves under a variety of short-term conditions is also described. One of the major problems in testing a cost-allocation model is that costs are rarely compiled by an operator at the level of an individual line or small groups of lines. As a result, sensitivity can be judged against systemwide cost estimation and against reasonableness of the results and ranges of the results for subgroups of lines. The sensitivity tests documented in this paper comprise prediction to other recent years, with and without internal recalibration: comparison of calibrated and projected models for a 2-year time lapse, and tests on the ability of the model to project costs for a package of service changes. Each of the tests indicated satisfactory performance by the model and demonstrated the ability of the model to identify the sources of changes in costs resulting from changes in service.

To assess alternative transit policies and service changes, it is highly desirable and necessary [if federal capital or operating funding is sought (*1*)] to be able to forecast the annual operating costs of the alternative policies and service changes. Most transit properties possess some form of cost model that can be used to estimate current or near-future operating costs. Most of these models use coefficients that are fixed at a point in time close to the present and require the use of variables describing system operation that can be estimated for an immediately upcoming time period. For example, an operating cost model may include a variable such as the number of pull outs per day, which can be determined only after runs are cut and vehicle assignments made. In addition, most cost models do not distinguish between fixed and variable costs (except in the original cost-allocation procedure), and most treat all elements of cost as continuously variable.

BACKGROUND

Before any analysis was attempted, current literature was researched and existing bus operating cost models were reviewed. There are three basic types of bus-operating cost models (2):

1. Type I—causal-factor models,
2. Type II—cost-allocation models, and
3. Type III—temporal-variation models.

Type I models break the cost into bus service, maintenance, and overhead components. Estimated quantities of these components required for bus operation are developed and multiplied by unit costs based on the actual or estimated market price of that component (e.g., drivers, buses, fuel, tires, etc.). These quantity estimates are multiplied by the appropriate unit costs, and the resulting products are summed to arrive at the transit cost. This process is similar to the budgeting process used to estimate costs in most industries. There are few examples of such models in practical use.

Type II models allocate the expenditures of each transit-system division based on aggregate measures of transit service, such as vehicle hours and vehicle miles. Unit costs are developed for these aggregate measures, which comprise the coefficients of the cost-allocation model. Most current models are of this type.

Type III models define cost as a function of time of day or day of week. The emphasis here is on differences in temporal labor costs and temporal vehicle costs that arise from differences in such items as deadheading, pullouts, use of part-time drivers, and so on. Few such models are currently used by transit agencies.

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TABLE 1 EXAMPLES OF EXISTING BUS OPERATING COST MODELS

	Variables and Coefficients						
Source	Vehicle Hours	Vehicle Miles	Peak Vehicles	Revenue	Days	Passengers	Pull Outs
Chicago Transit Authority[a]	11.13	0.28	20,059.22	0.06	–	–	–
University of Oklahoma[b]	–	Yes	Yes	–	Yes	–	–
St. Louis Model	Yes	Yes	Yes	–	–	Yes	–
Minneapolis-St. Paul[c]	9.90	0.31	1,353	–	–	–	–
Cash Flow Model, Miami[d]	–	Yes	–	–	–	–	–
Bus Planning, Miami[e]	22.39	1.10	–	–	–	–	–
The Scatchard Model[f]	25.42	1.74	–	–	–	–	–
The Gephart Model[g]	40.98	–	–	–	–	–	173.37

[a] See (*3*,p.241).
[b] See (*4*).
[c] See (*5*).
[d] See (*6*).
[e] See (*7*).
[f] See (*8*).
[g] See (*9*).

In Table 1 (*3–9*) are examples of cost-allocation models currently used at transit properties. Although a number of other models exist, there are few practical examples of Type I and Type III models. Described in this paper is an attempt to develop a methodology and to construct a model of bus operating costs based on cost allocation, with variables available from UTPS forecasting procedures, so that the model can be used for long-range and short-range costing. A specific attempt was made in the calibration procedure to develop a model that would estimate costs in constant dollars and for which adjustments could be made to reflect a change in the base year for the constant dollars. Some attempt was also made to deal with differential inflation within transit property operations. The model was also developed to distinguish between fixed and variable costs and to treat costs as noncontinuous functions where appropriate.

This bus-operating cost model is designed to allow the calculation of the operating expenses for bus operation associated with either increases or decreases in service. The model generates these estimates from projections of annual bus operating statistics based on the quantity of service for the whole bus system—that is, a summation of the data for each specific route—and can also be used in a long-range version with linear coefficients applied to estimates of service-level variables generated from UTPS forecasts.

DEVELOPING THE MODEL

The cost model described in this paper was developed to meet the following requirements:

1. To realistically reflect changes in the variable operating costs of a transit agency, while maintaining correct fixed costs for the operation;
2. To estimate both fully allocated and marginal costs for service and service changes;
3. To function with currently available UTPS data;
4. To use data readily available from an operator;
5. To function on a systemwide level; and
6. To provide line-by-line estimates of operating costs, irrespective of the accuracy of the underlying model.

The model described next was developed to satisfy the foregoing requirement and has been calibrated to data from the Southern California Rapid Transit District (SCRTD).

Most existing bus cost models are based on level-of-service variables primarily selected from vehicle hours, vehicle miles, passenger boardings, number of pullouts, peak-vehicle requirements, and revenue. The validity of using such variables has been established both through statistical analyses and conceptual argument. Cost-allocation models of this kind have led to the simple assumption that any budget item or expenditure line item can be set to vary with only one level-of-service variable. The model described here is no exception: the added complexity required for multiple-variable effects is not likely to be justified. This cost model is based on selecting a set of level-of-service variables that meet several criteria:

1. Variables are sufficient to forecast costs on all line items of the budget,
2. Variables provide responsiveness to different types of service that may be offered and to changes in service profile, and
3. Variables can be output or derived from standard urban transportation simulation procedures for long-range forecasting.

Criterion 1 is a judgment call, but seems to suggest that vehicle hours and vehicle miles alone are unlikely to be adequate. Criterion 2 also suggests use of additional variables that would provide some differentiation between services offered throughout the day and peak-period-only services. Criterion 3 leads to a rejection of a variable such as pull outs, which is not readily derived from long-range forecasting techniques.

Based on the foregoing criteria, the following four level-of-service measures were selected for the model: (*a*) annual vehicle miles, (*b*) annual service hours, (*c*) average weekday p.m. peak vehicles, and (*d*) annual passenger boardings. The model is a fixed/variable cost allocation model. Basically, the cost of each element of service is allocated to one of the level-of-service measures. The different elements of service are defined as the individual reported line items of expenditure, or small groupings of line items. Each line item is first defined as either variable—that is, the line item is expected to vary with changes in the service level measures—or fixed—that is, the line item should not change irrespective of service changes. Variable line items are then defined as varying either continuously with the selected service measure (e.g., fuel costs vary continuously with vehicle miles) or in steps (e.g., wage and fringe costs of transmission mechanics vary stepwise with vehicle miles; step size is defined as the annual cost of one transmission mechanic).

The stepwise element of the model is important because it reflects the fact that most positions in a transit agency are full-time positions and a change in cost will occur only when sufficient service is added or cut to trigger the addition or removal of an entire position. When part-time positions are available, the steps can be set to a half-time position cost, rather than a full-time position cost. Although it can be argued that service changes can occur during a fiscal year, potentially invalidating the stepwise concept, an agency is more commonly interested in the implications for a full year of operation instead of in the savings or costs for the balance of the year. Also, the stepwise characteristic is still valid in limiting cost changes to those resulting from a real capability to decrease the labor force or to operate increased service with the existing labor force.

When applied to the SCRTD, an additional refinement was built into the model that will also apply to any other multiple-division system. The SCRTD operates service out of multiple operating divisions, with minor maintenance undertaken at the operating divisions. Only major maintenance and repairs are undertaken at a central maintenance facility. Because it is not generally possible to assign an individual operator or service mechanic to more than one operating division, positions that exist at an operating/maintenance division can only change when service changes at the division are sufficient to add or delete a position. Therefore, each variable cost item is also identified as either division based or system based. If it is division based, then service changes must be estimated for this cost item at each division, and a determination made within each division of the changes in positions. System-based items are determined for the total of all changes within the entire system.

MODEL CALIBRATION

Procedure

To calibrate the model, it is necessary (*a*) to allocate each cost judgmentally to a service measure; and (*b*) to determine the budget lines, numbers of positions at each budget line, and the amounts of service for the calibration year. From these figures, the unit costs for each budget line item are calculated as follows.

When the costs are determined and allocated, the model can be used in two alternative ways. For short-range costing, the model has been constructed as a spreadsheet on which the individual budget items are preserved and costing is done by determining the number of steps triggered by the amounts of service under study. The costs of each step are then multiplied by the number of steps and the results summed to produce the total costs for the service. For long-range costing, a more conventional model application is undertaken because the detail for the line item costing is either not available or not sufficiently accurate to warrant this procedure. For the second application, coefficients (unit costs) are computed by summing the costs per vehicle mile, vehicle hour, peak bus, and passenger boarding, irrespective of step or continuous functions, to produce a model with the form

$$\text{Cost} = a_1 VMT + a_2 VHT + a_3 PKBS + a_4 PASS + FIX \tag{1}$$

where

VMT = annual vehicle miles of travel,
VHT = annual vehicle hours of travel,
$PKBS$ = average p.m. weekday peak bus requirement,
$PASS$ = annual passenger boardings, and
FIX = total annual fixed costs.

The model described in this paper was calibrated with data from the SCRTD FY 1986. SCRTD operates the majority of bus service for Los Angeles County, a region with a population of about 7.3 million. In 1983, SCRTD provided 331,500 daily service bus-miles and carried 1.47 million rides, which amounted to a total of 5.3 million passenger-miles. The SCRTD's total vehicle fleet is approximately 3,000, of which 2,500 vehicles are in active service (*9*). The bus operating costs in the FY 1986 model are based on the FY 1986 SCRTD organization, the SCRTD departments, and the projected account expenditures for FY 1986. The SCRTD annual budget for FY 1986 was used as the basic resource document. In addition, the June 1985 Revenue and Expense Statement (SCRTD) and inputs from the appropriate departments were used to subdivide some items of labor into more detailed components, and to provide estimates of the labor resources and costs for these. The projected operating statistics were supplied to SCRTD for the FY 1986 operations and are for 107,465,000 annual vehicle-miles, 7,585,000 annual vehicle-hours, 424,400,000 annual unlinked passenger trips, and an average weekday p.m. peak vehicle requirement of 1,987.

For FY 1986, with unit costs in calendar 1985 dollars, the model is

$$\begin{aligned}\text{Cost} = {} & 0.97{*}VMT + 25.82{*}VHT + 68088{*}PKBS \\ & + 0.1162{*}PASS\end{aligned} \tag{2}$$

Step Sizes

Step sizes are defined for those expenditure categories where costs vary with the level-of-service variable by increments, rather than continuously. For example, wages and fringes for operators (drivers) are allocated to vehicle hours. However, each saving of a vehicle hour does not generate a saving of operator costs, given union and contract rules, and how operators are assigned to service. In the model, it is assumed that a cost saving or an additional cost outlay is involved each time the change amounts to the equivalent of one half-time operator for the year. This change, in FY 1986, is estimated to occur when there is an increment (up or down) of 853 vehicle-hours. If a change in vehicle hours smaller than this amount takes place, no change in operator cost will be obtained. If a change larger than 853 hours annually is projected, a change in cost is assumed to occur. The change is determined by dividing the total projected change in vehicle hours by 853, and truncating the result to an integer value. This integer value represents the number of half-time operators saved by the change in vehicle hours. The cost savings are estimated by multiplying this number by the step cost of operator wages and fringe benefits. Two numerical examples should serve to illustrate the process. (Note that operator wages and fringe benefits are determined to have a FY 1986 step cost of $21,064.)

1. Cost savings from a reduction of 500 vehicle-hours annually—This value falls below the step size of 853 hours and therefore is assumed to provide no savings in operator wages and fringe benefits.
2. Cost savings from a reduction of 10,000 vehicle-hours annually at one operating division—The value of 10,000 is divided by 853, yielding the result of 11.72. This is truncated to an integer value of 11, indicating that 11 half-time equivalent operators can be saved by this reduction. Further, 11 half-time operators work 9,383 vehicle-hours annually, which is the number of vehicle hours for which there will be a cost saving. Total cost savings from operator wages and fringe benefits are obtained by multiplying $21,064 by 11, for a savings estimate of $231,704 in wages and fringe benefits. It should be noted that the further reduction of 617 (10,000 – 9,383) hours produces no additional cost savings on operators. It should also be noted that, because operators are assigned to divisions, this computation is only correct if all 10,000 vehicle-hours are saved at one division. If the vehicle hours were saved as 5,000 at each of two divisions, the steps would be 5 at each division, totaling 10 steps for a savings of $210,640.

Step sizes are based on primary categories: (*a*) an employee, (*b*) an operating division, and (*c*) a bus facility. Because the number of employees at the SCRTD varies from department to department and from category to category, the step size (in miles, hours, buses, or passengers) also varies among departments and categories. The average size of both an operating division and a maintenance operating division in FY 1986 is 153 peak buses.

Directly Variable Items

Directly variable items are much simpler than stepwise variable items. These are expenditures that can be assumed to vary with every increment or decrement of the level-of-service variable to which they are allocated. For example, fuel is allocated to vehicle miles as a directly variable item with a unit cost of $0.2521 in FY 1986. By allocating fuel as a directly variable item, it is assumed that each change of a vehicle mile will produce a cost change of $0.2521. Thus, a decrease of 1,000 vehicle-miles will save $252.10, and an increase of 10,000 vehicle-miles will increase costs by $2,521. This computation is always systemwide. The model contains very few line items that are directly variable.

Fixed Items

All remaining budget line items are considered to be fixed costs, and these are allocated, for fully allocated costing at the line level, to one of the four variables used by the model. As for the other expenditure items, unit costs are computed for each line item defined as a fixed cost. If a change in service is examined, by definition there will be no changes to total fixed costs. Therefore, the unit cost of each fixed-cost item is recomputed, to yield the same total fixed cost as before the change in service. For example, wages for the general manager's office are assigned as a fixed cost to peak buses, with a FY 1986 unit cost of $179.67. If a service change reduces peak buses from the FY 1986 value of 1,987 to 1,968, the unit cost for wages for the general manager's office increases to $181.40.

SUMMARY OF UNIT COSTS

In Table 2 a summary is provided of the unit and step costs produced by the FY 1986 calibration for average daily p.m. peak buses, annual total vehicle hours, annual total vehicle miles, and annual passenger boardings. Unit costs in Table 2 are in end-of-calendar-year 1985 dollars, assuming 4 percent inflation from July 1985 through June 1986. The definition of annual scheduled vehicle hours and annual scheduled vehicle miles is consistent with the definitions used by the SCRTD in preparing Section 15 Reports (*10*). These unit costs can be used to estimate operating costs for alternative service-level scenarios and for individual bus lines of the SCRTD system, but are subject to the constraints discussed next. Broader error bounds apply here than would apply to a fully programmed model using these calibrations. The step functions in the model make it necessary to assign service changes to the specific operating divisions where they will occur.

SENSITIVITY TESTS

Description

The model described in this paper was calibrated for the FY 1986 projected budget. A second version of the model was created that was calibrated to actual data for FY 1984 (*11*). The objective of the first sensitivity test was to perform an internal calibration of the FY 1984 coefficients to FY 1985 service levels and to project FY 1985 expenditures in order to determine the ability of the model to respond to changes in SCRTD structure and service levels, and to provide guidance on the frequency with which full calibration to a new budget or financial statement will be needed. After the update to FY 1985 was completed, a further update was undertaken to FY 1986 in order to compare the results with the FY 1986 full calibration. Because the period from FY 1984 to FY 1986 covers a number

TABLE 2 UNIT COSTS FOR THE FY 1986 BUS OPERATING COST MODEL

Allocation			Unit/Step			
To	By	Step Basis	Cost ($)	Marginal	Level	Source
Buses	Direct	1.0	75.4907	Yes	System	Facility maintenance supplies—radio
Buses	Fixed	1.0	43,640.6643	No	System	Most headquarter departments
Buses	Step	5.8	31,945	Yes	Division	Maintenance operating divisions—servicing
Buses	Step	31.5	42,645	Yes	System	Scheduling checkers
Buses	Step	33	31,771	Yes	Division	Maintenance operating divisions service—deep cleaning
Buses	Step	33.1	40,179	Yes	Division	Maintenance operating divisions—wheelchair service
Buses	Step	47	39,927	Yes	System	Facilities maintenance—electrical maintenance
Buses	Step	60.2	40,173	Yes	Division	Maintenance operating division—farebox maintenance
Buses	Step	110	40,025	Yes	Division	Maintenance operating divisions—special projects
Buses	Step	117	32,032	Yes	System	Central maintenance service
Buses	Step	142	275,925	Yes	System	Facilities maintenance—electrical, property, supplies
Buses	Step	142	50,168	Yes	System	Maintenance—general instruction
Buses	Step	153	750,139	Yes	Division	Transportation operating divisions
Buses	Step	153	44,121	Yes	System	Transportation services—radio dispatcher
Buses	Step	153	96,867	Yes	Division	Contracts and purchasing storekeeper
Buses	Step	153	729,656	Yes	Division	Maintenance operating divisions—miscellaneous supplies, additionals
Buses	Step	166	47,954	Yes	System	Central maintenance—central shop supplies
Hours	Fixed	1.0	0.1696	No	System	Transportation general—all
Hours	Fixed	1.0	0.3326	No	System	Transportation services—wages
Hours	Fixed	1.0	0.0079	No	System	Nondepartmental—fuel/lube, nonrevenue
Hours	Step	853	19,383	Yes	Division	Transportation operating divisions—operations
Hours	Step	853	1,681	Yes	Division	Nondepartmental—worker's compensation, operations
Hours	Step	216,714	34,400	Yes	System	Maintenance operating divisions—nonrevenue maintenance
Hours	Step	329,783	42,044	Yes	System	Scheduling—schedule makers
Hours	Step	421,400	44,002	Yes	System	Transportation services—street supervisors
Hours	Step	446,176	34,471	Yes	System	Police—transportation services inspections
Hours	Step	474,000	44,244	Yes	System	Transportation instructors, operator training
Hours	Step	632,083	31,084	Yes	System	Accounts and fiscal—payroll clerk
Miles	Direct	1.0	0.2366	Yes	System	Maintenance operating divisions—parts, lube, etc.
Miles	Direct	1.0	0.2703	Yes	System	Nondepartmental—fuel and taxes
Miles	Step	107,465	524	Yes	System	Nondepartmental expenses—expenses for property damage
Miles	Step	107,465	2,531	Yes	System	Nondepartmental expenses provided for property damage
Miles	Step	69,332	3,710	Yes	System	Nondepartmental worker's compensation, maintenance
Miles	Step	178,810	40,186	Yes	Division	Maintenance operating divisions—running repairs
Miles	Step	2,149,300	40,180	Yes	Division	Maintenance operating divisions—inspectors
Miles	Step	2,755,513	40,179	Yes	System	Central maintenance—running repairs
Miles	Step	2,904,459	40,189	Yes	System	Central maintenance—mechanical
Miles	Step	3,160,735	40,206	Yes	System	Central maintenance—electrical
Miles	Step	3,358,281	40,187	Yes	System	Central maintenance—body shop
Miles	Step	3,582,167	40,200	Yes	System	Central maintenance—transmissions
Miles	Step	3,960,185	39,984	Yes	System	Central maintenance—engine line
Miles	Step	4,477,708	40,209	Yes	System	Central maintenance—welding
Miles	Step	5,656,053	40,158	Yes	System	Central maintenance—cylinder head
Miles	Step	5,656,053	40,158	Yes	System	Central maintenance—paint shop
Miles	Step	7,676,071	40,215	Yes	System	Central maintenance—machine shop
Miles	Step	7,676,071	40,215	Yes	System	Central maintenance—sheet metal shop
Miles	Step	8,266,538	40,231	Yes	System	Central maintenance—frame shop
Miles	Step	8,266,538	40,231	Yes	System	Central maintenance—upholstery
Miles	Step	9,769,545	40,182	Yes	System	Central maintenance—systems
Miles	Step	13,433,125	40,125	Yes	System	Central maintenance—engine parts
Miles	Step	13,433,125	40,125	Yes	System	Central maintenance—engine teardown
Miles	Step	17,910,833	40,166	Yes	Division	Maintenance operating divisions—road failure
Miles	Step	21,493,000	40,033	Yes	System	Central maintenance—sign shop
Miles	Step	26,866,250	40,250	Yes	System	Central maintenance—tool and unit
Passenger	Direct	1.0	0.0011	Yes	System	Print shop—timetables
Passenger	Fixed	1.0	0.0070	No	System	Marketing and communication
Passenger	Fixed	1.0	0.0029	No	System	Customer relations (fixed)
Passenger	Step	163,231	524	Yes	System	Expenses for public liability
Passenger	Step	163,231	14,481	Yes	System	Provisions for uninsured public liability
Passenger	Step	4,715,555	29,678	Yes	System	Customer relations telephone clerks
Passenger	Step	12,482,353	34,470	Yes	System	Transit police passenger security
Passenger	Step	12,860,606	32,273	Yes	System	Accounting cash clerks
Passenger	Step	19,290,909	30,955	Yes	System	Marketing and communications ticket clerk

of organizational and service level changes, the procedure was believed to be quite a stringent test of the model's robustness.

The second sensitivity test aimed to determine the ability of the model to project costs for a package of service changes and to determine whether or not it is necessary to undertake an internal recalibration of the model whenever such a package of changes is examined. The test was also intended to provide a comparison between the existing cost model used by the SCRTD (*8*) (with costs reduced by 25 percent to account for fixed overhead costs) and the results from use of this model. The package of service changes was constructed by considering a potential list of service cuts that might be implemented with the goal of generating annual savings of $10 million in operating and maintenance costs.

Two sensitivity tests were designed to be executed for the procedure. First, determination of results of a simple application of the model was necessary, in which marginal costs were estimated and all step sizes were held the same as in calibration. This provided a comparison of the new cost model with the existing SCRTD model and also indicated what could be involved in application of the new cost model to small service changes. Second, the effect on the estimated cost savings if the model were internally recalibrated before completing the cost estimation needed to be determined. This test indicated the extent to which such recalibration may be necessary for short-range application of the model.

Application of the Procedures

Internal Recalibration of the Cost Model

The change in the Consumer Price Index (CPI) from the end of FY 1984 to the middle of FY 1986 was 4.6 percent for the Los Angeles standard metropolitan statistical area (SMSA) (*12*). FY 1984, FY 1985, and FY 1986 (projected) values of the level-of-service variables used in the cost model are given in Table 3, along with the final audited values for FY 1984—the calibration was done with actual data for the first three quarters of FY 1984 and projected data for the last quarter. The recalibration is unaffected by whether vehicle hours and vehicle miles are expressed as revenue, scheduled, or total values provided that the model is always applied with values consistent with the model calibration or recalibration.

In Table 4 the FY 1984 budgets are given for each type of variation for each service-level variable, along with the unit costs derived for FY 1984 for reference purposes. The CPI adjustment is then applied to determine the FY 1985 escalated budget, as given, and the budget values are then divided by the FY 1985 service-level values to obtain new unit costs. The latter two items are given in Table 4 as the escalated budget and the recalibrated unit costs. The same two calculations are also given for FY 1986, for which the CPI change from FY 1984 was determined to be 11.285 percent.

The result of the test, given in Table 4, is a model projection of total expenditure of $442,727,000 for FY 1985 compared with actual audited operating expenditures for FY 1985 of $439,903,899. The difference (overestimate) of $2,823,101 represents 0.64 percent of the FY 1985 actual expenditures. The same process for the FY 1986 estimated budget, using the FY 1986 estimated service level data used earlier to recalibrate the model, provides budget lines and coefficients that generate a total forecast budget of $481,256,000 compared with the SCRTD budget of $484,174,000. In this case, the difference (underestimate) is $2,918,000 and represents 0.60 percent of the SCRTD budget for FY 1986.

In Table 5 the final coefficients from Table 4 are summarized for the four service-level variables, and some shifting of cost between the service-level variables resulting from some internal reorganization of the SCRTD between FY 1984 and FY 1986 is shown. As a result, the match between the internally recalibrated figures and the actual calibration of FY 1986 is not as close as the overall budget projections would indicate. However, the results are encouraging in terms of the robustness of the model and the ability of the internal recalibration to produce sensible results.

Direct Model Application Without Recalibration

SCRTD planning staff identified a number of service cuts intended to total $10 million in terms of FY 1986 operating cost cuts for a full year. These service cuts were originally costed using a version of the SCRTD model (*8*) that had been adjusted to approximate marginal costs. In Table 6 the calculations for each line or period on a line are summarized and compared with the SCRTD cost model estimates of cost savings. The line costs in Table 6 do not reflect the potential savings within a division or across the entire SCRTD that would be achieved when the service cuts are summed together; these additional savings are as follows:

Division	*Operating Cost ($)*
1	25,100
3	349,800
5	69,400
6	479,100
7	48,200
8	333,800
9	685,500
10	319,200
12	603,700
15	62,000
16	687,500
18	827,200

Note that systemwide costs total $3,423,100, so that a total of systemwide and division costs is $7,913,600.

The full set of proposed service reductions is estimated at

TABLE 3 ACTUAL AND PROJECTED ANNUAL LEVELS OF SERVICE FOR FY 1984, 1985, AND 1986

	Value			
Variable	FY 1984 Calibrated	FY 1985 Actual	FY 1986 Estimated	FY 1984 Audited
P.M. peak buses	2,063	2,009	1,987	1,992
Vehicle hours	7,152,000	7,041,642	7,585,000[a]	7,062,585
Vehicle miles	95,122,000	91,959,736	107,465,000[a]	93,031,164
Passengers	465,400,000	497,158,321	424,400,000	465,637,732

[a] These are total miles and hours, while all other entries are revenue miles and hours.

TABLE 4 COMPUTATION OF RECALIBRATED COSTS AND ESCALATED BUDGETS

Variable	Type	FY 1984 Unit Cost ($)	FY 1984 Budget ($000)	FY 1985 Budget ($000)	FY 1985 Unit Cost ($)	FY 1986 Budget ($000)	FY 1986 Unit Cost ($)
Peak buses	Direct	79.01	163.0	170.3	82.57	181.4	87.93
	Fixed	33,279.69	68,656.0	71,745.5	35,712.06	76,403.8	38,451.85
	Step	22,497.33	46,412.0	48,500.5	24,141.63	51,649.6	25,993.76
Subtotal		55,856.03	115,231.0	120,412.0	59,936.26	128,228.0	64,533.54
Vehicle hours	Fixed	0.59	4,250.0	4,441.3	0.63	4,729.6	0.62
	Step	23.80	170,185.0	177,843.3	25.26	189,390.4	24.97
Subtotal		24.39	174,435.0	182,285.0	25.89	194,120.0	25.59
Vehicle miles	Direct	0.57	54,491.0	56,943.1	0.60	60,640.3	0.64
	Step	0.49	46,644.0	48,743.0	0.53	51,907.8	0.48
Subtotal		1.06	101,135.0	103,785.0	1.13	120,415.0	1.12
Passenger boardings	Direct	0.0011	490.0	512.1	0.0011	545.3	0.0012
	Fixed	0.01	4,078.0	4,261.5	0.0086	4,538.2	0.0107
	Step	0.06	30,065.0	31,417.9	0.06	33,457.8	0.0788
Subtotal		0.0711	34,633.0	36,245.0	0.0729	38,493.0	0.0907
Total cost/ budget ($)			425,434,000	442,727,000		481,256,000	

$7,913,600 by this operating cost model, instead of the $10,407,000 derived from the current SCRTD model (*8*). The estimate from the new model is approximately 24 percent lower than the SCRTD model. The model also shows that there are significant intra-division and systemwide economies possible in a group of service changes of this size, given that the difference between the line-by-line costs and the division/ systemwide costs is about $1.5 million in a set of service changes initially costed at $6.4 million. Gross costs of these service changes are $10,412,900 with revenues of $2,499,200. An investigation of the detailed differences in the cost estimates revealed that most of the difference results from fractions of positions that could not be saved in reality and should not, therefore, be counted by any cost model.

The second notable element of this cost model is shown in Table 7, which gives the sources of the costs identified in Table 6 and indicates the cost attributable to each element. Of the gross costs for the service changes listed in these tables, approximately $2.8 million is derived from materials savings, such as fuel and parts, and from savings on property damage and public liability. These savings would be achieved without any other action on the part of the SCRTD than by cutting the service. All of the remaining $7.6 million in costs are from labor positions or labor-related costs. For example, $6.1 million in savings will accrue from the 144 operators used to operate the services in Table 6. However, if these operators are not laid off, only a small fraction of the savings would occur from reductions in hours paid.

Model Application With Recalibration

To determine the effects of internal recalibration of the model for a significant set of service changes, the changes used in the preceding section were reestimated using a single recalibration for the entire package. The primary effects of internal recalibration will be on the fixed costs, which were not included in the estimation of the service-change costs described in the previous section. However, some changes may occur in step sizes as a result of the service changes. These can be identified readily by using Table 7, which indicates those line items that are changed and which implicitly identifies all unchanged labor categories.

The internal recalibration was undertaken by recomputing each stepwise line item in the spreadsheets, which determined the change in FY 1986 cost, the change in the base, and the

TABLE 5 SUMMARY OF FINAL COEFFICIENTS FROM INTERNAL RECALIBRATION AND FULL CALIBRATION OF FY 1986

	Coefficient/Unit Cost ($)			
Variable	FY 1984 Calibrated	FY 1985 Internally Recalibrated	FY 1986 Internally Recalibrated	FY 1986 Calibrated
Peak buses	55,969	59,936	64,534	68,088
Vehicle hours	24.390	25.887	25.593	25.82
Vehicle miles	1.063	1.129	1.121	0.97
Passengers	0.0744	0.0729	0.0907	0.1162

TABLE 6 SUMMARY OF COSTS FOR SPECIFIC LINE AND PERIOD SERVICE CUTS, BASED ON THE FY 1986 OPERATING COST MODEL

Line No.	Division No.	Service Day	Operating Cost ($)	Cumulative Cost ($)	SCRTD Operating Cost ($)	Cumulative SCRTD Cost ($)
203	3	Weekday	48,400	48,400	98,000	98,000
203	3	Saturday	1,000	49,400	19,000	117,000
203	3	Sunday	1,100	50,500	21,000	138,000
203	3	All	94,100	94,100	138,000	138,000
225/226	18	Saturday	134,400	228,500	233,000	371,000
208	3	Sunday	25,700	254,200	34,000	405,000
175	3	Saturday	24,200	278,400	55,000	460,000
175	3	Sunday	800	279,200	30,000	490,000
175	3	Saturday/Sunday	46,000	300,200	85,000	490,000
208	3	Saturday	23,000	323,200	29,000	519,000
192/194	16	Weekday	427,700	750,900	636,000	1,155,000
250/253	10	Sunday	21,600	772,500	52,000	1,207,000
430	6	Weekday	44,400	816,900	83,000	1,290,000
130	12	Sunday	64,300	881,200	151,000	1,441,000
259	9	Sunday	42,100	923,300	103,000	1,544,000
236	8	Sunday	21,600	944,900	63,000	1,607,000
161	8	Weekday	181,600	1,126,500	333,000	1,940,000
205	12	Saturday	56,200	1,182,700	130,000	2,070,000
205	12	Sunday	14,500	1,197,200	52,000	2,122,000
205	12	Saturday/Sunday	70,700	1,197,200	182,000	2,122,000
220	7	Sunday	40,800	1,238,000	91,000	2,213,000
487/491	9	Saturday	85,800	1,323,800	168,000	2,381,000
487/491	9	Sunday	40,100	1,363,900	115,000	2,496,000
487/491	9	Saturday/Sunday	132,700	1,370,700	283,000	2,496,000
166/168	8	Sunday	42,300	1,413,000	129,000	2,625,000
208	3	Weekday	190,300	1,603,300	137,000	2,762,000
208	3	All	242,400	1,606,700	200,000	2,762,000
462	1	Sunday	41,400	1,648,100	92,000	2,854,000
236	8	Saturday	41,900	1,690,000	103,000	2,957,000
236	8	Saturday/Sunday	84,500	1,711,000	166,000	2,957,000
293	16	Weekday	454,100	2,165,100	255,000	3,212,000
262	9	Sunday	38,800	2,203,900	114,000	3,326,000
225/226	18	Weekday	769,700	2,973,600	1,126,000	4,452,000
225/226	18	All	968,400	3,037,900	1,359,000	4,452,000
268	3	Sunday	39,900	3,077,800	97,000	4,549,000
130	12	Saturday	59,300	3,137,100	130,000	4,679,000
130	12	Saturday/Sunday	148,400	3,161,900	281,000	4,679,000
250/253	10	Saturday	36,900	3,198,800	82,000	4,761,000
250/253	10	Saturday/Sunday	79,600	3,219,900	134,000	4,761,000
271	12	Weekday	164,900	3,384,800	299,000	5,060,000
147	12	Saturday	16,800	3,401,600	44,000	5,104,000
147	12	Sunday	(4,900)	3,396,700	23,000	5,127,000
147	12	Saturday/Sunday	33,000	3,417,800	67,000	5,127,000
488	9	Sunday	18,000	3,435,800	54,000	5,181,000
274/276	9	Weekday	495,200	3,931,000	767,000	5,948,000
42	18	Sunday	99,600	4,030,600	203,000	6,151,000
259	9	Saturday	37,100	4,067,700	88,000	6,239,000
259	9	Saturday/Sunday	100,200	4,088,700	191,000	6,239,000

TABLE 6 *continued*

Line No.	Division No.	Service Day	Operating Cost ($)	Cumulative Cost ($)	SCRTD Operating Cost ($)	Cumulative SCRTD Cost ($)
434	6	Sunday	83,200	4,171,900	198,000	6,437,000
220	7	Saturday	36,500	4,208,400	77,000	6,514,000
220	7	Saturday/ Sunday	77,300	4,208,400	168,000	6,514,000
482	16	Sunday	38,200	4,246,600	123,000	6,637,000
267	9	Sunday	17,500	4,264,100	63,000	6,700,000
209	5	Sunday	54,200	4,318,300	110,000	6,810,000
493	9	Sunday	17,900	4,336,200	36,000	6,846,000
215	18	Saturday	15,900	4,352,100	57,000	6,903,000
262	9	Saturday	54,800	4,406,900	100,000	7,003,000
262	9	Saturday/ Sunday	118,400	4,431,700	214,000	7,003,000
434	6	Saturday	79,500	4,511,200	174,000	7,177,000
434	6	Saturday/ Sunday	180,700	4,529,200	372,000	7,177,000
158	15	Sunday	17,200	4,546,400	71,000	7,248,000
154	8	Sunday	36,200	4,582,600	86,000	7,334,000
183	15	Sunday	35,400	4,618,000	68,000	7,402,000
169	15	Saturday	35,400	4,653,400	100,000	7,502,000
423	8	Weekday	88,000	4,741,400	223,000	7,725,000
119/ 126	18	Saturday	52,100	4,793,500	108,000	7,833,000
438	18	Weekday	96,300	4,889,800	197,000	8,030,000
265/ 275	12	Weekday	374,400	5,264,200	588,000	8,618,000
211	5	Saturday	14,100	5,278,300	56,000	8,674,000
434	6	Weekday	638,400	5,916,700	993,000	9,667,000
434	6	All	883,600	5,981,200	1,365,000	9,667,000
256	10	Sunday	31,400	6,012,600	95,000	9,762,000
103	5	Sunday	14,900	6,027,500	44,000	9,806,000
255	10	Sunday	32,200	6,059,700	66,000	9,872,000
576	10	Weekday	361,500	6,421,200	535,000	10,407,000

change in the number of positions. This computation produced a new estimated step size for all steps. Using these new step sizes in the calculations for the division and systemwide costs of the service changes produced a revised estimate of net costs of $8,061,900, an increase of $148,300, or 2 percent of the original cost estimate. Based on this, it appears that internal recalibration of the model is unnecessary, at least for service changes on the order of 50 peak buses, and $10 million in gross costs.

LIMITATIONS ON THE MODEL APPLICATION

The primary limitation on the use of this cost model is that the step costs and unit costs are based on projected or reported labor and organization for the agency for the calibration year. Thus, the model cannot account for significant reorganization or changes in labor productivity or costs. Furthermore, if significant changes are proposed in service levels, the model should be recalibrated to adjust all step sizes and the unit costs for fixed costs to take into account the changes in the base over which the various costs are spread. Recalibration can potentially include a review of the allocation of certain cost items, together with the addition of any new line items introduced in a subsequent year's budget. Experience with this model to date indicates that it is quite robust under normal year-to-year changes, and may not require recalibration for a number of years as long as relatively small changes are made each year.

If service levels are increased, the bases of peak buses, vehicle hours, vehicle miles, and passenger boardings are likely to increase; unit costs of fixed budget items will decrease, and step sizes of stepwise variables will increase until a reorganization takes place. If service levels are decreased, each of these bases are also likely to decrease; unit costs of fixed budget items will increase, and step sizes of stepwise variables will decrease, again, until a reorganization takes place. When service changes are small, unit cost changes are unlikely to have a significant effect on the estimation of costs, as shown by the sensitivity tests reported in this paper. Major system changes, in excess of ±10 percent or more of current service, can be expected to significantly affect the accuracy of the estimated costs.

CONCLUSIONS

The cost-allocation model presented in this paper uses multiple-step functions related to specific positions in a transit operation. The model can provide accurate projections of short-range transit costs and is being used for projecting long-range

TABLE 7 SOURCES OF COSTS FOR THE SERVICE CHANGES IN TABLE 4

Source Level	Department	Item	Quantity	Allocated Cost ($)
Systemwide	Facilities maintenance	Supplies—radios	52	3,926
	Scheduling	Schedule checkers	1	42,645
	Facilities maintenance	Electronics maintenance	1	39,928
	Maintenance operating divisions	Nonrevenue maintenance	1	34,400
	Maintenance operating divisions	Parts, lubricants	–	1,030,705
	Nondepartmental expenses	Fuel and taxes	–	1,177,723
	Nondepartmental expenses	Workmen's compensation—maintenance	62	229,999
	Nondepartmental expenses	Expenses and provisions for property damage	40[a]	122,200
	Central maintenance	Running repairs mechanic	1	40,179
	Central maintenance	Mechanical maintenance, mechanic	1	40,189
	Central maintenance	Electrical maintenance, mechanic	1	40,206
	Central maintenance	Body shop mechanic	1	40,187
	Central maintenance	Transmission mechanic	1	40,200
	Central maintenance	Engine line mechanic	1	39,983
	Print shop	Timetable printing	–	5,769
	Nondepartmental expenses	Expenses for public liability	31[a]	16,239
	Nondepartmental expenses	Provisions for public liability	31[a]	448,904
	Customer relations	Telephone clerks	1	29,678
Division 1	Transportation operations division	Operators	1[b]	38,766
	Nondepartmental expenses	Workmen's compensation operations	1[b]	3,363
Division 3	Transportation operations division	Operators	9[b]	348,897
	Nondepartmental expenses	Workmen's compensation operations	9[b]	30,263
	Maintenance operating division	Running repairs mechanic	1	40,186
Division 5	Transportation operating divisions	Operators	3[b]	116,299
	Nondepartmental expenses	Workmen's compensation operations	3[b]	10,088
Division 6	Maintenance operating division	Service workers	1	31,945
	Transportation operating division	Operators	18[b]	697,794
	Nondepartmental expenses	Workmen's compensation operations	18[b]	60,525
	Maintenance operating division	Running repairs mechanic	3	120,559
Division 7	Transportation operations division	Operators	2[b]	77,533
	Nondepartmental expenses	Workmen's compensation operations	2[b]	6,725
Division 8	Transportation operating division	Operators	11[b]	426,430
	Nondepartmental expenses	Workmen's compensation operations	11[b]	36,988
	Maintenance operating division	Running repairs mechanic	2	80,373
Division 9	Transportation operating division	Operators	22.5[b]	872,243
	Nondepartmental expenses	Workmen's compensation operations	22.5[b]	75,657
	Maintenance operating divisions	Running repairs mechanic	3	120,559
Division 10	Maintenance operating divisions	Service workers	1	31,945
	Transportation operating division	Operators	12[b]	465,196
	Nondepartmental expenses	Workmen's compensation operations	12[b]	40,350
	Maintenance operating divisions	Running repairs mechanic	1	40,186
Division 12	Maintenance operating divisions	Service workers	1	31,945
	Transportation operating division	Operators	19.5[b]	755,944
	Nondepartmental expenses	Workmen's compensation operations	19.5[b]	65,569
	Maintenance operating divisions	Running repairs mechanic	3	120,559
Division 15	Transportation operating division	Operators	3[b]	116,299
	Nondepartmental expenses	Workmen's compensation operations	3[b]	10,088
Division 16	Maintenance operating divisions	Service workers	1	31,945
	Transportation operating divisions	Operators	18[b]	697,794
	Nondepartmental expenses	Workmen's compensation operations	18[b]	60,525
	Maintenance operating divisions	Running repairs mechanic	2	80,373
Division 18	Maintenance operating divisions	Service workers	1	31,945
	Transportation operating division	Operators	25[b]	969,159
	Nondepartmental expenses	Workmen's compensation operations	25[b]	84,063
	Maintenance operating divisions	Running repairs mechanic	4	160,745

[a] Number of accidents involving property damage (average).
[b] Full-time equivalent positions.

costs. The model automatically ignores changes in service levels that are too small to generate cost increments or decrements and permits costs to be split between fixed and variable cost items. The model is therefore able to be used to produce both marginal allocated costs and fully allocated costs.

Sensitivity tests reveal that this bus cost model is a robust short-term model that produces acceptably accurate results (comparing systemwide costs) even under conditions of some significant amount of reorganization and service change. Changes of less than 10 percent in service levels do not require recalibration of the model, as shown by the documented sensitivity tests. The tests also indicate that, as should be expected, the model produces lower estimates of cost than are produced by a standard linear-in-coefficients model of bus costs.

An interesting side benefit of the short-range version of the model is that it provides identification of the specific budget items that contribute to a cost savings or cost increase. This property allows the model to provide additional information about the financial implications of alternative policies with respect to hiring and firing related to service changes and can readily reveal the consequences of different policies on the cost structure of transit service.

Overall, it appears that the cost allocation model tested here is appropriately sensitive, robust under fairly substantial organizational changes in a transit agency, able to provide new insights into the implications of service changes for both manpower and material supplies of a transit operation, and accurate to an acceptable level. However, the model is probably most exciting because of its basis in manpower and potential for future enhancements that could enable it to indicate changing relationships in an organization chart, changes in requirements for supervision and training, and changes in work rules and union contracts.

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Short Turning on Transit Routes

PETER G. FURTH

It is common to have certain trips short turn—begin or end partway along the route rather than at the route terminus)—in recognition of the characteristic drop in passenger volume at the end of a transit route. Because many passenger demands can be met by a trip following either a full-length or short-turn pattern, schedule coordination between the patterns is essential. Possible schedule coordination modes are described. Algorithms are presented for finding the schedule offset between the patterns that will balance loads and minimize overall cost. It is shown that even when overall capacity exceeds volume on every link, there may still be no schedule for which the trips of one or more patterns are not systematically overcrowded.

On heavy-demand transit routes the conventional strategy of operating all trips locally from one end of the line to the other can often be far less efficient than more complex strategies that are better tailored to a route's particular passenger origin-destination (O-D) distribution. When the O-D pattern shows a gradual drop in volume from the peak volume point to either end of the route, a commonly used strategy is short turning—having some trips cover only the more heavily used part of the route. Although the short-turn strategy is commonly used in the transit industry, a formal analysis of the strategy is lacking in the literature. The strategy is described by Furth and Day (*1*) who cite some examples of its use and compare it with other strategies, such as zoning, restricted and semirestricted service, and express service. The only known analysis of the strategy is Ceder's (2). However, only aggregate volumes and capacities are considered in this approach, and passenger behavior in the case of overlapping service patterns is not addressed. As will be seen, this approach can easily lead to systematic overcrowding on some trips, while excess capacity exists on others. In the absence of a satisfactory published analysis, one might expect that this strategy is not applied as often as it could be, and that when applied, it is not always designed with maximum efficiency.

As defined in this paper, all trips in a short-turn system operate locally with no boarding or alighting restrictions. The short-turn system includes one full-length pattern and one or more short-turn patterns. Each pattern operates at regular intervals, and each short-turn pattern is entirely overlapped by the next longer pattern. All patterns are assumed to cover the peak volume segment of the route. A common configuration is for all the patterns to have the same central business district (CBD) terminus and to have turnback points at different distances from the CBD. However, our framework permits turnbacks at both ends of the corridor, and is therefore applicable to crosstown and through routes, as well as radial routes. A top priority is to minimize fleet size to serve a given demand. Level of service also plays a role at a higher level of design. In this paper terminology appropriate to bus systems will be used; however, the analysis can be applied to rail transit systems as well because the strategy does not rely on overtaking.

SCHEDULE COORDINATION MODES FOR SHORT TURNING

Consider a route with a full-length pattern and a single short-turn pattern. Passengers whose trips lie entirely within the inner zone of the corridor (the portion served by the short-turn pattern) can use either pattern and constitute the choice market. Other passengers, who have at least one trip end outside the inner zone, can use only the full-length pattern and constitute the full-length market. The two patterns compete for choice market patrons who will use the first bus that comes along unless it is overcrowded, a condition that the design described here aims to avoid. Thus, within the inner zone, the load on any trip (of either pattern) will depend on the elapsed time since the previous trip (of either pattern), therefore, the schedules of the two patterns must be coordinated in order for the loads to be regular.

When there is a single short-turn pattern, this need for coordination can most easily be accomplished if the two service patterns operate with the same frequency. The two patterns will then alternate in serving the inner zone, and the schedule offset between the patterns will determine how much of the choice market will be carried on each pattern. For example, if the offset is one-half of the headway, then each pattern will carry one-half of the choice market. However, such a schedule will lead to unequal loads. This is most easily seen in the inbound direction: vehicles serving the full-length pattern will arrive at the turnback point already partially loaded, while vehicles serving the short-turn pattern will begin there empty. Unless the full-length pattern uses larger vehicles than the short-turn pattern, balancing loads between the two patterns requires that a short-turn trip lead each full-length trip by a small fraction of the full-length pattern's headway, so that the short-turn trips capture most of the choice market. An example of such a schedule (inbound) would be for full-length trips to pass the turnback point at times 8, 16, 24 min, and so on, while the short-turn trips leave the turnback point at times 6, 14, 22 min, and so on.

Schedule coordination is especially needed in the outbound direction on radial routes. Without proper schedule coordination, choice market passengers can overcrowd the full-length trips. Almost all passengers desiring to board after the point of overcrowding will be forced to use the short-turn pattern. Those traveling to the outer zone will then have to transfer at the turnback point to the next full-length trip. This problem of "induced transfers" is discussed by Wilson et al. (*3*). Without proper schedule coordination in the inbound direction, choice passengers will again overcrowd the full-length trips, but this will not occur until the bus reaches the inner zone; therefore,

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passengers who are turned away can use the next short-turn trip without difficulty. However, if the full-length pattern extends beyond the short-turn pattern on both sides, then induced transfers can occur in both directions. Although some transit systems, notably subway systems, may tolerate such unbalanced loads and induced transfers, most transit systems want to avoid them by designing the schedule so that passengers can board the first bus serving their destination without causing overcrowding.

Effective schedule coordination is achieved in a multipattern system when each trip (save trips on the shortest pattern) follows a trip of the next shorter pattern, so that each pattern's frequency is a multiple of the next longer pattern's frequency. Let pattern p be defined as the pth longest pattern ($p = 1,\ldots,P$), and let zone p be the portion of the route covered by patterns $1,\ldots,p$ only. The "scheduling mode" may then be expressed as $1{:}r_2{:},\ldots,{:}r_P$, where r_p is the relative frequency of pattern p, and where r_p is a multiple of r_{p-1} for $p > 1$. An example of a 1:2 schedule is for full-length trips to pass the turnback point every 7 min, while short-turn trips leave the turnback point at 3 and 6 min after each full-length trip. Then each full-length trip will carry 7 min of the full-length market and 1 min of the choice market, while each short-turn trip carries 3 min of the choice market only.

An important characteristic of a mode is the relative (vehicular) trip volume in each zone, given by

$$T(p) = \sum_{i=1}^{p} r_i \tag{1}$$

CAPACITY

The operation of competing patterns within the same corridor suggests a special treatment of capacity constraints. In the customary style of deterministic analysis, randomness in both passenger and vehicle arrival patterns is accounted for through the use of design load factors (maximum allowable expected occupancy at any point as a fraction of a vehicle's nominal capacity), which are set low enough to prevent overcrowding most of the time. In short-turn systems, different parts of the system are affected by randomness in different ways; therefore, it seems reasonable to use different load factors accordingly. For example, in a 1:1 mode, overcrowding of full-length trips has more severe consequences for excluded passengers than overcrowding of the short-turn pattern, especially in the outbound direction. This suggests that the design load factor of the full-length pattern should be less than that of the short-turn pattern.

Given the scheduling mode and vehicle design capacities of each pattern, the aggregate passenger carrying capacity per full length pattern headway in zone p is given by

$$C(p) = \sum_{i=1}^{p} r_i k_i \tag{2}$$

where k_i is the design capacity of vehicles on pattern i, reflecting both vehicle size and the design load factor.

DESIGN FRAMEWORK

The decisions to be made in finding the best short-turn pattern include the schedule coordination mode, location of turnback points, the vehicle sizes, full-length pattern headway (h), and the peak direction offsets for the $T(P) - 1$ short-turn trips that repeat every interval h. (Reverse direction offsets are ignored because they can usually be scheduled independently of the peak direction offsets by appropriate distribution of layover time between the route endpoints.) Because of the limited number, feasible coordination modes, turnback points, and vehicle sizes will be considered as exogenous parameters in this paper, leaving h and the offsets as the decision variables in the optimization problem. Before formulating the optimization problem, the next section offers guidance on the choice of the exogenous parameters. By varying these parameters, a full range of designs can be generated and compared to complete the design process.

The primary objective is to minimize fleet size. Given the schedule coordination mode, the location of the turnback points, and the vehicle capacities, this means h has to be maximized. The main passenger impact of short-turn design is on waiting time because in-vehicle time is only slightly affected, if at all. Therefore, the secondary objective is to minimize wait time (equivalent to minimizing h) for a given fleet size. If a combined objective of operator and passenger cost is desired, it is a simple matter to parametrically vary h (as well as the other parameters) and to calculate the cost and travel time impacts to obtain an optimal trade-off.

SCREENING FOR DESIGN PARAMETERS

The ideal behind short turning is to match the provided capacity with the demand. An obvious constraint is that the total provided capacity in any zone must exceed the peak passenger volume in that zone; that is,

$$C(p)/h \geq V(p) \qquad \text{for } p = 1,\ldots,P \tag{3}$$

where $Vs(p)$ equals peak passenger volume in zone p.

Given a choice of scheduling mode, vehicle capacities, and location of turnback points, Equation 3 provides an upper bound on h as shown by

$$h \leq \min_{p} \frac{C(p)}{V(p)} \tag{4}$$

Choice of Schedule Coordination Mode

One indication of the efficiency of a design is E, which is the relative excess capacity at the peak point as shown by

$$E = \frac{C(P)}{hV^*} - 1 \tag{5}$$

where V^* is the peak point volume. Large values of E are inefficient, indicating wasted capacity at the peak point. Transit agencies usually have a maximum allowable headway, h_{max}, that must be maintained by the full length pattern (because it alone serves the outermost zone). Substituting h_{max} for h in Equation 5 yields the minimum attainable value of E for a particular choice of mode and vehicle capacity. Configurations with a minimum attainable E that is above some threshold E_{max} can be screened out as inefficient. This device can be used to limit the number of modes to be considered. If $\bar{k} = C(P)/T(P)$ equals the average vehicle design capacity, then requiring that $E \le E_{max}$ implies that

$$T(P) \le \frac{(1+E_{max})\ V^*\ h_{max}}{\bar{k}} \qquad (6)$$

In a heavy demand corridor, h_{max} is typically 12 min maximum, and peak volume is rarely more than 1 vehicle-load per 2.5 min. Considering these worst case values with $E_{max} = 0.15$, Equation 6 yields $T(P) < 5.5$. There are only 11 scheduling modes that meet this requirement: 1:1, 1:2, 1:3, 1:4, 1:1:1, 1:1:2, 1:1:3, 1:2:2, 1:1:1:1, 1:1:1:2, and 1:1:1:1:1. With lighter passenger volumes, the upper limit for $T(P)$ will often be 2, 3, or 4, for which there are only 1, 3, and 6 possible modes, respectively. Thus, the choice of scheduling mode is quite restricted.

Choice of Turnback Point

Equation 3 can serve as a guideline for selecting turnback points, given the scheduling mode and vehicle capacities. By first applying Equation 3 to the (still undefined) innermost zone (zone P), the right hand side is V^*, and an upper bound on h is obtained. If the headway must be in whole minutes, h should be rounded down to the next whole minute. Then, given h, Equation 3 provides upper bounds on the peak volume of each zone. The outermost stop j at which the volume profile in either direction exceeds the volume upper bound for zone p is an inner bound location for the turnback point of pattern p, in the sense that the turnback point may be no closer to the peak volume point. As a first guess for an efficient design, the turnback points at their respective inner bounds are located. If analysis of the resulting configuration (described in later sections) proves it to be infeasible with the given h, turnback point locations can be moved farther out, or h can be lowered, resulting in a new set of inner bound locations.

The process of choosing turnback inner bound locations can be compared to choosing the locations where a freeway should add and drop lanes in response to volume changes. This approach is satisfactory with freeways because of the ability of vehicles on a multilane freeway to transfer without penalty between lanes. However, on a multipattern transit route, transfers between patterns are highly undesirable. Therefore, simply comparing overall capacity with overall volume is inadequate for transit design; instead, each pattern must be analyzed individually in the light of passenger behavior.

ANALYSIS OF 1:1 SCHEDULING MODE

A complete analysis will be given for the simplest short-turn system, one with a 1:1 schedule coordination mode. The turnback point is given. The analysis relies on a stop-level O-D matrix that can be measured directly using a survey, or that can be estimated using methods described by Simon and Furth (*4*) and Ben-Akiva et al. (*5*).

From the O-D matrix, the volume profile can be constructed for each direction. The peak volume, V^*, occurs at the point PVP^*. The O-D matrix is then partitioned into Market 1, the full-length market that contains O-D pairs whose outermost zone is zone 1, and Market 2, the choice market; volume profiles of each market are constructed separately. The variables used in this analysis are given as follows:

Pattern p = pth longest pattern;
Zone p = portion of route served only by patterns $1,\ldots,p$;
Market p = portion of the route O-D matrix served by patterns $1,\ldots,p$;
c_p = cycle time for pattern p (including recovery time);
$C(p)$ = aggregate capacity per interval h in zone p;
f = offset = interval between a full-length trip and the preceding short-turn trip;
h = full-length pattern headway;
J_p = set of (stop-to-stop) segments in zone p;
k_i = design vehicle capacity for pattern i;
$\bar{k}$ = mean design vehicle capacity;
M_p = size of market p (peak direction);
P = number of patterns, index of innermost (shortest) pattern;
PVP_p = peak volume point for market p (peak direction);
PVP^* = peak volume point for combined markets;
q = frequency of full-length pattern = $1/h$;
r_p = number of pattern p trips per interval h;
R = capacity ratio = k_2/k_1;
$T(p)$ = number of trips in zone p per interval h;
v_{pj} = market p volume in segment j (peak direction);
v_p = market p peak volume;
$V(p)$ = peak volume in zone p (combined markets);
V^* = volume at peak point (combined markets);
w = overall average wait time, peak direction; and
z = relative offset = f/h.

There are two trips that repeat every interval h: a full-length trip and a short-turn trip. In the outer zone, only the full-length trip operates, and its loading constraint is

$$v_1 h \le k_1 \qquad (7)$$

In the inner zone, loading constraints apply to both trips. It is assumed that on average, both patterns travel at the same speed over the same segment, which implies that the schedule offset is the same at every stop in the inner zone. (See the section on other practical considerations.) Because the short-turn trip carries only choice passengers, its peak load point will be PVP_2 regardless of the offset, therefore, the loading constraint is

$$v_2(1-z)h \le k_2 \qquad (8)$$

However, the peak volume point of full-length trips is a function of z because z determines the share of choice market using that trip. For example, if $z = 1$, its peak volume point will not be in the inner zone; if $z=1$, its peak volume point will be PVP^*. Therefore every stop in the inner zone must be considered:

$$(v_{1j} + zv_{2j})h \leq k_1 \qquad \text{for all } j \in J_2 \tag{9}$$

By replacing h with its reciprocal q, the problem may be stated thus:

$$\min q$$

$$\text{s.t. } q \geq v_1/k_1 \tag{10}$$

$$q \geq (1-z)v_2/k_2 \tag{11}$$

$$q \geq (v_{1j} + zv_{2j})/k_1 \qquad \text{for all } j \in J_2 \tag{12}$$

$$0 \leq z \leq 1 \tag{13}$$

The constraints are shown in Figure 1. This linear optimization in q and z is easily solved. For a particular segment j, let $z(j)$ denote the value of z at the intersection of Equation 11 and Equation 12; $z(j)$ is thus the offset that balances the load in segment j:

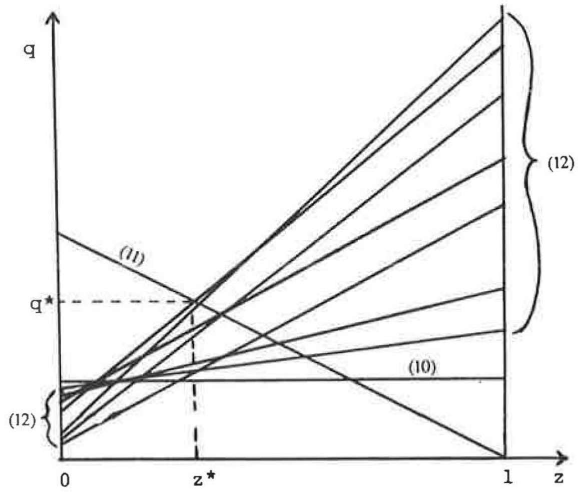

FIGURE 1 Constraints for 1:1 mode.

$$z(j) = \frac{Rv_2 - v_{1i}}{Rv_2 + v_{2j}} \tag{14}$$

where the capacity ratio $R = k_2/k_1$. Let j^* be the segment with the smallest $z(j)$. Then the optimal z is $z^* = max[z(j^*), 0]$. The optimal q, q^*, is then the smallest bound given by Equations 10 and 11. However, when Equation 10 is binding, the design will generally prove inefficient, and the short-turn pattern should probably be extended.

The average wait time in the peak direction, w, is given by

$$w = \frac{h}{2}\left\{M_1 + M_2\,[z^2 + (1-z)^2]/(M_1 + M_2)\right\} \tag{15}$$

INCORPORATING WHOLE-MINUTE SCHEDULING CONSTRAINTS

Thus far, the analysis has treated frequency and offset as continuous variables. However, in practical terms departures usually must be scheduled in minutes, or, in a few systems, in one-half minutes, yielding a discrete set of acceptable headways and offsets. If $1/q^*$ does not belong to the set of acceptable headways, it must be rounded down. Let h be the rounded headway, and then let $q = 1/h$. [It is also possible to begin the design procedure here with h as the (rounded down) upper bound provided by Equation 4.] Now the problem is to find, for the given q, an acceptable offset that is feasible with respect to the constraints represented in Equations 11 and 12. Equation 11 yields a lower bound on the relative offset, z_{low}, and Equation 12 yields a family of upper bounds, $z_{up}(j)$:

$$z_{low} = 1 - \frac{k_2 q}{v_2} \tag{16}$$

$$z_{up}(j) = \frac{qk_1 - v_{1i}}{v_{2j}} \tag{17}$$

Let $\hat{j}$ be the segment with the smallest $z_{up}(j)$ (it is likely, but not necessary, that j^* and $\hat{j}$ will be the same), then the range of feasible offsets is

$$z_{low}h \leq f \leq z_{up}(\hat{j})h \tag{18}$$

If there is more than one acceptable offset in this range, the value closest to z^*h will best balance the loads. However, if there is no acceptable offset in this range, then h must be lowered to its next acceptable value, possibly increasing the fleet size. This will in turn enlarge the range for the offset, making it very likely that a feasible offset can be found without lowering the headway a second time. Alternatively, the turnback point or points can be moved farther out, widening the range for f; this may or may not increase operating cost, depending on whether additional vehicles are needed to cover the extra distance.

When a solution is found, the next lower value of h should be examined to see whether it leaves the fleet size unchanged and yields an offset range that contains a feasible offset. If so, passenger waiting time can be lowered at very little cost. Also, as pointed out by Ceder (*2*), consideration should be given as to whether the short-turn pattern can be extended without increasing the fleet size. Extending the pattern will tend to make the offset range broader, but will also tend to make it rise; therefore, it is necessary to check that it still contains an acceptable offset.

DEADHEADING AND INTERLINING TO REDUCE FLEET SIZE

During peak periods, the reverse direction passenger volumes are often small enough that they can be served by the full-length trips only or by some other subset of the trips. In such a case, the short-turn patterns not needed can deadhead. Deadheading reduces the cycle time but otherwise leaves the analysis unchanged.

Another way to reduce operating costs when the patterns share a common terminus is to interline patterns. (The interlining analysis is the same whether the short-turn cycle involves deadheading or not. Interlining with routes outside the short-turn system can also be done, but this is beyond the scope of the paper.) If the two patterns are operated without interlining, the required fleet size is $<c_1/h>^+ + <c_2/h>^+$, which can be expressed as

$$Int(c_1/h) + Int(c_2/h) + <m_1>^+ + <m_2>^+ \quad (19)$$

where $m_p = mod(c_p/h)$, $Int(x)$ and $mod(x)$ are the integer and fraction portions of x, respectively; and $<>^+$ indicates rounding up to the next whole number.

If two routes or patterns are interlined with no restriction on the offset, then the minimum length of the composite cycle is $(c_1 + c_2)$. Therefore, the required fleet size, when the offset is unrestricted, is $<(c_1 + c_2)/h>^+$, which can be expressed as

$$Int(c_1/h) + Int(c_2/h) + <m_1 + m_2>^+ \quad (20)$$

However, the need to balance loads in a short-turn system restricts the offset to a single value or a narrow range of values. An interlined schedule with a fixed offset is shown by the time-space diagram in Figure 2. Both the full-length and the short-turn pattern have departures at every headway h. The time period illustrated is the evening peak; accordingly, short-turn departures from a common CBD terminus lead full-length departures by the offset f.

As the diagram shows, the minimum allowed cycle time is $(c_1 + c_2 + s_2)$, where s_2 equals the wait time required at the common terminus after completion of a short-turn cycle. Therefore, the fleet size required when interlining with a fixed offset equals the following

$$Int(c_1/h) + Int(c_2/h) + <m_1 + m_2 + s_2>^+ \quad (21)$$

As shown in Figure 2, s_2 must be between 0 and h, and must satisfy the equation $c_2 + s_2 = f + Ih$, where I is an integer. The solution is

$$s_2 = def_h(c_2 - f) \quad (22)$$

where $def_h(y)$ is the amount needed to round up y to a multiple of h. (For example, $def_4(17) = 3$.)

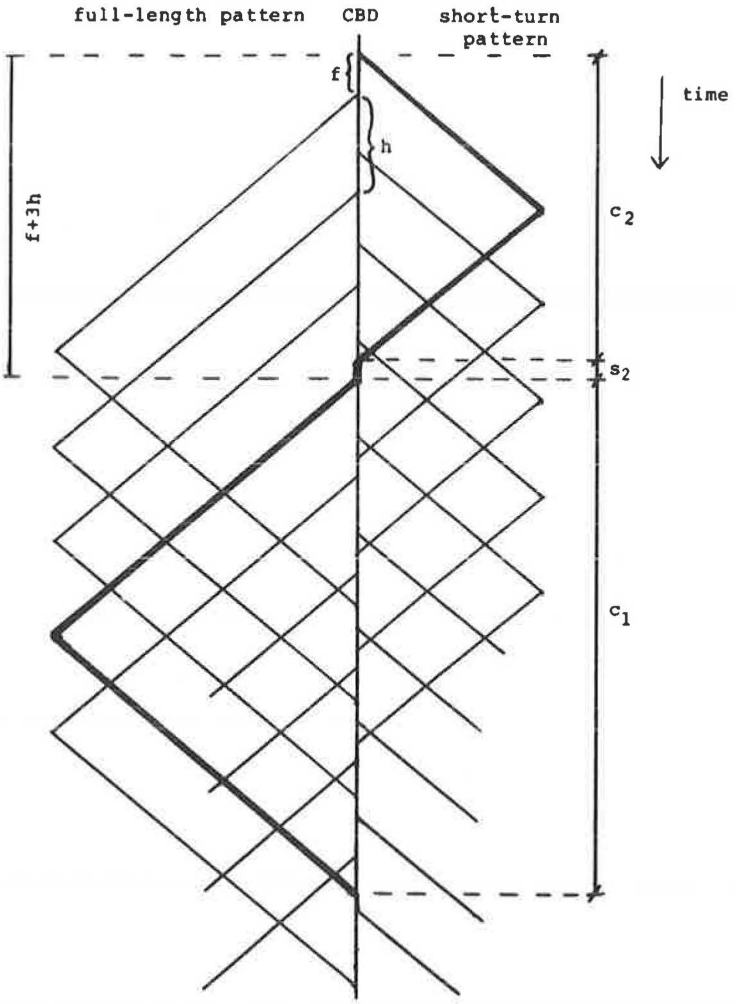

FIGURE 2 Interlining cycle for 1 : 1 mode.

Because it requires the insertion of slack time s_2 into the composite cycle, fixing the offset reduces the potential of interlining for saving vehicles. Consider the case of two randomly chosen routes with a common terminus and headway and independent cycle times. If the cycle times are considered as continuous random variables, then m_1 and m_2 are independent and uniformly distributed on the interval (0,1). If the offset is unrestricted, then, comparing Equations 19 and 20, interlining can save a bus if

$$<m_1 + m_2>^+ \; < \; <m_1>^+ + <m_2>^+ = 2 \tag{23}$$

This condition is met if $(m_1 + m_2) \leq 1$; the probability is

$$\int_0^1 \int_0^{1-x} dydx = \tfrac{1}{2} \tag{24}$$

However, if the routes must maintain an exogenously determined offset f, which will also be treated as a continuous and independent random variable, then s_2 is also uniformly distributed between 0 and 1 and is independent of m_1 and m_2. In this case, a bus can be saved by interlining if $<m_1 + m_2 + s_2>^+ \leq 1$; the probability is

$$P[m_1 + m_2 + s_2 < 1] = \int_0^1 \int_0^{1-x-y} dzdydx = 1/6 \tag{25}$$

Thus, the presence of an exogenously determined offset greatly reduces the chances that interlining will save a bus. In fact, interlining can require an extra bus if $[<m_1 + m_2 + s_2{}^+] \geq 2$. (The probability of this occurrence is also 1/6.) If there is some flexibility in the choice of offset, the probability of saving a bus will increase.

OTHER PRACTICAL CONSIDERATIONS

A special case that can emerge from the design is for the relative offset to be zero, implying that the full-length pattern should not carry any of the choice market. This would theoretically be accomplished by having full-length trips immediately follow short-turn trips. This arrangement is impractical for many reasons that include the need for full-length trips to make all the stops that the short-turn trips make in order to avoid overtaking them. A more practical way of keeping choice passengers off full-length trips is for full-length trips to simply prohibit boarding within the inner zone in the inbound direction, and similarly to prohibit alighting within this zone in the outbound direction. With this policy, described by Furth and Day (*1*) as "restricted zonal service," passengers no longer have a choice of patterns, eliminating the need for coordinating schedules; therefore, the two patterns may be scheduled with different headways, which can lead to further efficiencies. Design methods for this strategy are discussed by Furth (*6*).

One of the assumptions of this analysis is that the offset will be the same throughout the inner zone. (Of course, there will be random variations, which are accounted for in deterministic analysis by the design load factor. This paragraph is concerned with systematic changes in offset.) However, in the inbound direction, because the offset is generally smaller than one-half of the headway, full-length trips will generally make fewer stops than short-turn trips in much of the inner zone; therefore, full-length trips will tend to catch up with the leading short-turn trip. This can be modeled by treating the expected offset at each stop as a function of both the initial offset and the demand profile; however, such precision seems unwarranted. A sufficient adjustment for the inbound schedule might be to consider f as the average desired offset, and to make the initial offset slightly longer. In the outbound direction, there is less of a tendency for short-turning to cause bunching because the schedule will be constructed in such a way that all vehicles will pick up approximately one busload of passengers in the CBD, the primary collection area.

Experience in the transit industry indicates that proper supervision is necessary for the successful implementation of a short-turn strategy. Without supervision, the driver of a short-turn trip, who is scheduled to lead a full-length trip, might purposefully follow the full-length trip instead and carry a very light load while causing overcrowding on the full-length trip. Offsets in the outbound direction are the most critical, for reasons discussed earlier; fortunately, these are usually the easiest to enforce because there are usually dispatchers at the downtown terminus. However, if street traffic is so heavy and headways so small that bunching cannot be prevented, a routing strategy that does not depend on the schedule offset should be used, such as restricted zonal service.

The short-turn strategy lends itself well to a distance-based fare structure. Because people making interzonal trips must use the full-length pattern, a higher fare can be charged on the longer pattern. To avoid penalizing those whose entire trip lies in the outer zone, fares for outbound boardings in the outer zone could be reduced. Such a policy will certainly affect the choice of inner-zone passengers. Those who would prefer to wait for a short-turn trip rather than pay the fare differential effectively leave the choice market and become a third market called the short-turn market. If the fraction diverted to the short-turn market is a constant, d, for all O-D pairs in the inner zone, then the variable z in Equations 8, 9, 14, 16, and 17 should be replaced with $z(1 - d)$. If different O-D pairs have different diversion factors, the loading constraints should be modified to explicitly account for three different markets (the full-length market, the short-turn market, and the net choice market), each with its own volume profile.

This analysis assumes demand rates and run times constant over a period of time of roughly 90 min or more. If, instead, they are variable, the closed-form solutions no longer apply, and fleet size must be determined from a more general approach, such as Salzborn's (*7*) or Ceder's and Stern's (*8*). However, the need for schedule coordination remains, and this need, along with the restriction (to avoid passenger confusion) that turnback locations remain constant, greatly restricts the search for an optimal schedule.

DESIGN FOR OTHER SCHEDULE COORDINATION MODES

Design for other scheduling modes follows the same procedures as for the design of the 1:1 mode. Steps for this design are summarized as follows:

1. The material on screening provides guidance on the initial choice of turnback points and coordination mode. An upper bound on h is also given.
2. Partition the route O-D matrix into P markets, where market p is that portion of the O-D matrix with an outermost zone p.
3. There are T^* trips that repeat every interval h. Their sequence is determined by the basic strategy of short turning: for $p<P$, a pattern p trip must follow a pattern $p+1$ trip. Index the trips according to the order they pass the peak point, with the full-length (Pattern 1) trip as trip T^*. Trip 1 will always be a pattern P trip. Then define the relative offset for trip t as z_t, which equals the fraction of h by which trip t follows the preceding trip in the peak direction. Construct the loading constraint or family of loading constraints for each trip in each zone that the trip operates, considering the reverse direction as well. These constraints include as unknowns h and z_t for $t=1,\ldots,T^*$. (z in the fifth section of the paper is what is referred to as z_2 in this section.) These constraints are easily constructed because the sequence of trips is known. Replace h with its reciprocal q, and add the constraints $\sum z_t = 1$ and $z_t \geq 0$ for all t.
4. Solve the problem (linear in q and z_t) of minimizing q subject to the constraints of Step 3, yielding an upper bound for $h = 1/q$. (Alternatively, fix h at the upper bound resulting from screening.) Round h down, if required, by a whole minute constraint, and solve the loading constraints for offset upper bounds. Round down these upper bounds in accordance with any integer constraints, and then sum them. If the sum equals or exceeds h, there is a feasible solution. If not, lower h and repeat, or change modes or turnback points.
5. For complex modes, the number of theoretically possible deadheading and interlining options can be very large. However, the number of interesting options will usually be small enough for each to be analyzed.

This approach will be illustrated with the 1:3 mode. As with the 1:1 mode, there are 2 patterns, therefore, the O-D matrix is partitioned into two markets. There are four trips that repeat every interval h. Trips 1, 2, and 3 are short-turn trips, and Trip 4 is the full-length trip. The loading constraints are as follows. For Trip 4 in the outer zone

$$v_1 h \leq k_F \tag{26}$$

For Trips 1,..,3 in the inner zone

$$v_2 h z_t \leq k_2 \qquad \text{for } t = 1,\ldots,3 \tag{27}$$

For Trip 4 in the inner zone

$$(v_{1j} + z_4 v_{2j})h \leq k_1 \qquad \text{for all } j \in J_2 \tag{28}$$

The direct constraints on the offsets are

$$z_1 + z_2 + z_3 + z_4 = 1 \tag{29}$$

$$z_t \geq 0 \qquad \text{for } t = 1,\ldots,4 \tag{30}$$

With a little manipulation, these constraints are all linear in $q(=1/h)$ and z_t.

Due to symmetry, in the unrounded solution: $z_1 = z_2 = z_3 = (1-z_4)/3$; therefore, the problem may be cast in terms of two variables, z_4 and q. The reason for distinguishing the offsets of multiple trips of the same pattern is that they may differ in the rounded solution. For example, suppose that after solving for h and rounding down, h equals 12 min, the upper bound for z_1, z_2, and z_3 equals 4 min and the upper bound for z_4 equals 2 min. Because the sum of these upper bounds exceeds 12, there are several solutions including those in which z_1, z_2 and z_3 are not all equal.

EXAMPLE

The inbound O-D matrix for a hypothetical 20-stop route is given in Figure 3. Figure 4a shows the volume profile derived from this O-D matrix. The minimum cycle times for routing patterns beginning at selected points and ending at the CBD (Stop 20) are shown as follows:

Turnback Point	*Cycle Time (min)*
1	84
2	76
3	72
4	66
5	62
6	58
7	54
8	50
9	46

The nominal vehicle capacity is 60 for all patterns, and headways must be in whole minutes. Without short turning, the peak volume of 580 passengers per hour requires 6-min headways and a fleet of $\langle 84/6\rangle^{+} = 14$ buses.

In this example, only the 1:1 mode will be analyzed. The screening process for choosing a turnback point will be demonstrated first. Given the equal vehicle design capacities of 60, the zonal capacities are $C(1) = 60$ and $C(2) = 120$. Applying Equation 3 to the Zone 2, the upper bound for h is 120 passengers divided by 580 passengers per hour, equalling 12.4 min, which rounds down to $h = 12$ min. Next, application of Equation 3 to Zone 1 yields the upper bound $V(j) \leq$ (60 passengers)/(12 min) = 300 passengers/hr. The outermost stop where the volume exceeds this limit is Stop 9; therefore, Stop 9 is the innermost stop that will be considered as a turnback point.

This simple solution provides enough aggregate capacity to meet the aggregate demand at every point and requires only $\langle 84/12\rangle + \langle 46/12\rangle^{+} = 7 + 4 = 11$ buses. However, as this example will demonstrate, this solution is not feasible when loading constraints on the individual patterns are considered.

The O-D matrix is partitioned into the choice and full-length markets, as shown in Figure 3. From the row and column totals of the two resulting submatrices, volume profiles for the two markets are constructed in Table 1. The computation of $z(j)$ is illustrated in Table 1. The minimum value is $z(j^*) = 0.226$, where j^* is Stop 11. The meaning of $z(j^*)$ is shown by Figure 4. In Figure 4a the volume profiles for the two markets are shown. The peak volume of the short-turn market (420 per hour) is

TABLE 1 VOLUME PROFILES AND RELATIVE OFFSETS

	Stop																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Full-Length Market																				
On	70	30	40	40	30	40	30	50	–	–	–	–	–	–	–	–	–	–	–	–
Off	–	–	–	–	10	10	–	20	10	–	10	25	25	20	20	20	20	30	20	90
v_{1j}	70	100	140	180	200	230	260	290	280	280	270	245	220	200	180	160	140	110	90	0
Choice Market																				
On									100	70	80	60	70	70	70	50	60	30	–	–
Off									–	–	5	15	30	30	40	40	50	80	70	300
v_{2j}									100	170	245	290	330	370	400	410	420[a]	370	300	0
Total volume	70	100	140	180	200	230	260	290	380	450	515	535	550	570	580	570	560	480	390	0
$z(j)$									0.269	0.237	0.226	0.246	0.267	0.278	0.292	0.313	0.333			
$h = 11$																				
$z_{up}(j)$									–[b]	–[b]	0.234[b]	–[b]	–[b]	–[b]	–[b]	–[b]	–[b]			
$h = 10$																				
$z_{up}(j)$									0.80	0.47	0.367	0.397	0.42	0.43	0.45	0.49	0.52			

[a] 420 = v_2^*.

[b] Superscript [b] ≥ $z(j)$ and therefore > 0.234.

To / From	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	TOTAL ON
1	6	5	-	4	3	-	2	7	6	5	3	3	4	5	3	14	70
2	4	5	-	6	1	-	1	2	2	-	1	1	-	1	1	5	30
3				5	2	-	2	3	3	3	3	3	2	3	2	9	40
4				5	2	-	2	3	3	2	3	2	3	3	3	9	40
5					2	-	1	2	3	2	2	2	2	4	2	8	30
6							2	3	3	3	3	3	2	3	2	16	40
7							-	2	2	2	2	2	2	4	3	11	30
8							-	3	3	3	3	4	5	7	4	18	50
Subtotal off stops 1-8	10	10	-	20	10	-	10	25	25	20	20	20	20	30	20	90	330
From																	TOTAL ON
9							5	15	11	8	7	6	6	9	8	25	100
10									10	8	8	7	5	6	5	21	70
11									9	7	9	7	5	9	7	27	80
12										7	7	5	5	7	5	24	60
13											9	7	10	9	7	28	70
14												8	10	15	7	30	70
15													9	15	10	36	70
16														10	10	30	50
17															11	49	60
18																30	30
Subtotal off stops 9-18	-	-	-	-	-	-	5	15	30	30	40	40	50	80	70	300	660
TOTAL OFF	10	10	-	20	10	-	15	40	55	50	60	60	70	110	90	390	990

FIGURE 3 Example of an O-D matrix.

much higher than that of the full-length market (290 per hour). In Figure 4b, 22.6 percent of the choice market is added to the full-length market to become the volume profile for the full-length pattern, while the short-turn pattern's profile represents 77.4 percent of the choice market. Both profiles now have the same peak volume, albeit at different points. This peak volume of 325 per hour calls for a headway of 11.07 min, which rounds down to $h = 11$ min.

Because the headway was rounded down by such a small amount, a small offset range is expected. z_{low} is found to be 0.221. In Table 1, $z_{up}(j)$ is calculated for every inner zone stop; the lowest value, 0.234, governs. (Because $z_{up}(j)$ is known to be greater or equal to $z(j)$ some of these calculations become unnecessary.) By multiplying these bounds by $h = 11$, the offset range is 2.43 to 2.57 min.

Suppose that a half-minute offset is acceptable. Then $f = 2.5$ min is chosen as the offset, and fleet size can now be calculated. Without interlining, the fleet size is $\langle 84/11\rangle^+ + \langle 46/11\rangle^+ = \langle 7.64\rangle^+ + \langle 4.18\rangle^+ = 8 + 5 = 13$. Next, considering interlining, calculate $s_1 = def_{11}(46 - 2.5) = 0.5$ so the fleet size needed with interlining is $\langle(84 + 46 + 0.5)/11\rangle^+ = \langle 11.86\rangle^+ = 12$.

However, if whole-minute offsets are required, there are two choices: lower the headway to 10 min, or move the turnback point farther out. If $h = 10$ (with the same turnback point), $z_{low} = 0.143$ and the lowest $z_{up}(j)$, calculated in Table 1, is 0.367. Multiplying by h, the offset range is 1.43 to 3.67 min, with two integer solutions possible: $f = 2$ or 3 min. The number of buses needed without interlining is $\langle 84/10\rangle^+ + \langle 46/10\rangle^+ = 14$. Taking $f = 2$, $s_1 = 0$ is obtained, and the number of buses needed with interlining is $\langle(84 + 46 + 0)/10\rangle^+ = 13$.

An alternative to lowering the headway is to move the turnback point farther back. Using an electronic spreadsheet

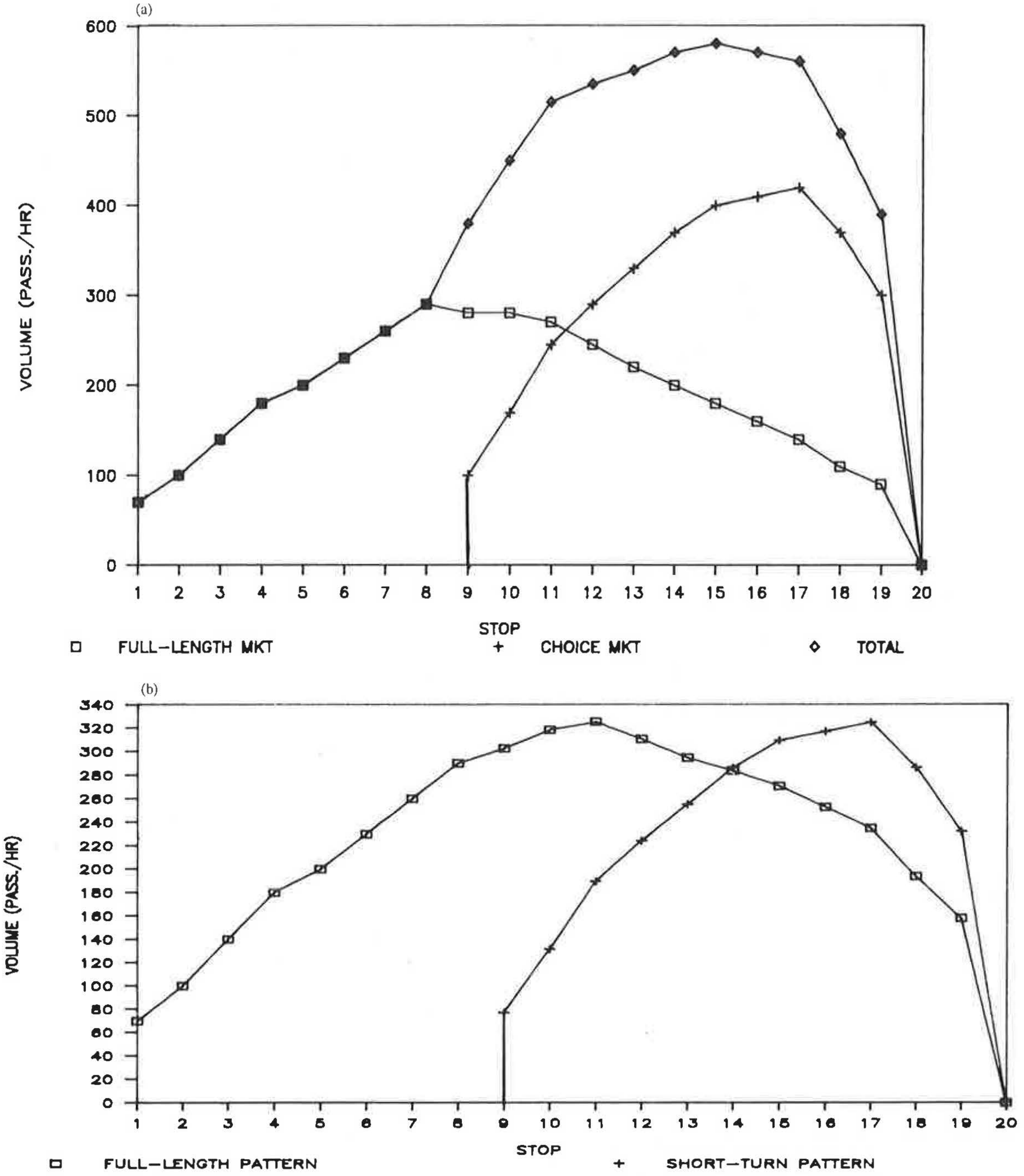

FIGURE 4 Volume profiles: (a) market profiles, and (b) pattern profiles with 22.6 percent offset.

makes the calculations for alternative turnback points easy to perform. As stated earlier, as the turnback point is moved outward, the relative offset range both rises and widens. In addition, a greater headway may become feasible (as it is in this case because a 12-min headway is feasible if the turnback is extended to Stop 6).

In Table 2 the offset range, fleet size, and average waiting time for $h = 10$, 11, and 12 min are shown as the turnback point is extended back from Stop 9. Where the offset range includes one or more whole-minute offsets, the required fleet size is shown. An (*i*) next to the given fleet size indicates where an interlining has saved a bus. Observe that not only is the "naive solution" with its 11-bus fleet infeasible, but the 12-bus solution is also infeasible when whole-minute offsets are required. Among the many solutions requiring 13 buses, the lowest wait-time solution has a turnback at Stop 6 with $h = 11$ min. For an examination of a trade-off between fleet size and wait time, the superior solutions (minimum wait time for a given fleet) are indicated. It is also interesting to note that of the 16 short-turning solutions, six show a savings through interlining, and of these, only 3 would show a savings (if there were no flexibility in the choice of offset), in close agreement with the predicted

TABLE 2 OFFSET RANGE AND FLEET SIZE FOR DIFFERENT HEADWAYS AND TURNBACK POINTS

Turn-back Stop	z	$h = 10$ min				$h = 11$ min				$h = 12$ min			
		f_{low}	f_{up}	N	$\bar{w}$	f_{low}	f_{up}	N	$\bar{w}$	f_{low}	f_{up}	N	$\bar{w}$
9	0.226	1.5	3.6	13(i)	3.8	2.3	2.5	–[a]	4.2	–	–	–	–
8	0.308	2.0	4.7	14	3.5	3.0	4.0	13	3.8	–	–	–	–
7	0.350	2.3	5.1	14(i)	3.3	3.3	4.6	13	3.6	–	–	–	–
6	0.395	2.7	5.4	15	3.1	3.7	5.2	13(i)	3.4[b]	4.7	4.9	–[a]	3.7
5	0.423	2.9	5.6	15(i)	3.0	3.9	5.4	14	3.3	4.9	5.3	13	3.6
4	0.447	3.2	5.8	16	2.9	4.2	5.6	14	3.2	5.2	5.5	–	–
3	0.466	3.4	5.9	16(i)	2.8	4.4	5.8	15	3.0	5.4	5.8	–	–
2	0.474	3.5	6.0	16(i)	2.7[b]	4.5	5.9	15	3.0	5.5	5.9	–	–
1	0.5	3.8	6.2	17(i)	2.5[b]	4.8	6.2	16	2.8	5.8	6.2	14	3.0[b]

Note: h = headway; f_{low}, f_{up} = lower, upper bound of offset range (min); N = fleet size required; z = balancing relative offset; and $\bar{w}$ = average wait time (min). Also (i) means interlining saved a vehicle.

[a] N=12 if noninteger offset is allowed.

[b] Superior solutions (minimum wait time for a given fleet size are given for an examination of trade off between fleet size and wait time.

1-in-6 average. This example illustrates how the flexibility afforded by the offset range increases the chances that interlining will save a bus.

The final bus savings in this example was not very large, as the example was meant to illustrate some of the concepts behind short-turn design rather than demonstrate the strategy's value for saving vehicles. Examples showing remarkable vehicle savings can easily be constructed and are probably unnecessary because the value of the strategy is well proven in transit systems across the nation. In a study of a Los Angeles short-turning bus route described by Furth et al. (*9*), the route would need 35 vehicles without short-turning, but need only 26 in the 1:1 mode configuration currently operated. Application of the procedures described in this paper yielded a more efficient 1:1 configuration requiring only 24 buses. The 1:2 mode was also examined, and the best configuration with that mode required 27 buses.

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Effects of Fare and Other Factors on Express Bus Ridership in a Medium-Sized Urban Area

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Ridership data for the express bus service in Knoxville, Tennessee, for the time period of September 1977 through August 1984 were analyzed to identify the effects of fare and other factors on transit usage. Most of the riders of the express bus service were employees of the Tennessee Valley Authority (TVA). The ridership data were adjusted for seasonal variation and fare was adjusted for inflation. A multiple regression analysis helped identify the significant independent variables. A model with the three independent variables of miles of travel, fare, and employment level was fairly accurate in predicting changes in daily ridership. The regression coefficients of the independent variables of the model were used to derive demand elasticity coefficients. The elasticity coefficient for fare, which was estimated to be –0.522, is higher than those revealed by other studies.

The purpose of this study is to quantify the effects of fare and other factors on express bus ridership in a medium-sized urban area. The Knoxville Transit's (K-TRANS) express bus ridership from January 1979 through August 1984 was used in developing a multiple regression model to explain the variations in ridership. Elasticity measures for each significant variable in the model were derived using the coefficients developed by regression analysis. The elasticities of transit use with respect to fare and vehicle miles of service are compared with those revealed by other studies.

HISTORY OF K-TRANS EXPRESS BUS SERVICE

Since December 1973, the Tennessee Valley Authority (TVA) and K-TRANS have held an agreement to encourage ridesharing in the city of Knoxville. At that time, K-TRANS began operating several express bus routes that were oriented to the TVA work schedule. Before October 1981, the agreement specified a minimum level of return for the express routes, and TVA was to pay any difference from this minimum if the collected revenue from fare fell below this level. TVA was also paying a 35 percent ticket discount to its employees. TVA's payment for meeting the guaranteed level of return averaged approximately $5,100 per month during the 12-month period before the discontinuation of the agreement in October 1981. In an attempt to regain lost revenue from the cancellation of the guaranteed payment, K-TRANS raised fares in October 1981. The subsidized ticket price increased from $0.585 to $0.845 for TVA employees. The previous fare increase had occurred only 7 months earlier in March 1981 when the discounted ticket price was raised from $0.4875 to $0.585. The price remained at the October 1981 level of $0.845 for TVA employees until July 1984 when K-TRANS lowered the discounted price to $0.65 in the hope of increasing ridership and revenue. Actual subsidized cost per ride in current dollars for TVA employees and the cost per ride in 1974 dollars are given in Table 1. The 1972 dollar cost is calculated by dividing fare by the urban consumer price index (CPIU).

TABLE 1 COST PER RIDE FOR TVA EMPLOYEES

Year	Quarter	Cost in Actual Dollars	Real Cost in 1972 Dollars
1979	1	0.3900	0.1884
	2	0.3900	0.1821
	3	0.3900	0.1763
	4	0.3900	0.1713
1980	1	0.3900	0.1649
	2	0.3900	0.1592
	3	0.4875	0.1952
	4	0.4875	0.1903
1981	1	0.4930	0.1875
	2	0.5850	0.2174
	3	0.5850	0.2113
	4	0.8450	0.3010
1982	1	0.8450	0.2985
	2	0.8450	0.2941
	3	0.8450	0.2886
	4	0.8450	0.2880
1983	1	0.8450	0.2881
	2	0.8450	0.2846
	3	0.8450	0.2812
	4	0.8450	0.2788
1984	1	0.8450	0.2758
	2	0.8450	0.2728
	3	0.6754	0.2163

Since the discontinuation of TVA's guarantee for minimum return, K-TRANS has attempted to minimize losses by eliminating underutilized express routes. In October 1981, K-TRANS operated 17 express bus routes. In August 1984, only 10 express routes were still in operation. The vehicle miles traveled declined by 41 percent between the third quarter of 1981 and the third quarter of 1983. The service levels are given in Table 2.

The average number of rides TVA employees made per day on the express buses decreased by 70 percent from January

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TABLE 2 NUMBER OF BUSES AND SERVICE MILES PER DAY

Year	Quarter	Number of Buses	Service Miles Per Day
1979	1	16.00	653.23
	2	16.00	664.00
	3	16.00	652.76
	4	16.00	655.45
1980	1	16.67	694.70
	2	17.00	708.41
	3	17.00	709.08
	4	17.00	698.61
1981	1	17.00	707.67
	2	17.00	703.00
	3	17.00	707.00
	4	16.00	666.17
1982	1	14.00	571.52
	2	14.00	588.00
	3	14.00	582.16
	4	12.00	509.00
1983	1	12.00	503.60
	2	11.33	452.18
	3	10.00	419.76
	4	10.00	422.44
1984	1	10.00	423.55
	2	10.00	423.96
	3	10.00	424.63

1979 to August 1984. In January 1979 the number of daily rides was approximately 1,100 as compared to 300 in August 1984. The decline in ridership may be attributed primarily to the fare increases and cuts in service. However, there are also several other factors that may have influenced ridership, which include the following:

- TVA employment in Knoxville,
- Vanpools,
- Cost of driving an automobile,
- Cost of riding a competitive bus service,
- Traffic congestion,
- Parking costs, and
- Adverse weather conditions.

It is obviously difficult to determine how much influence each of these variables has had on ridership. Regression analysis will be utilized to determine the relationship between ridership and some of the aforementioned variables.

MULTIPLE REGRESSION MODEL FOR ESTIMATING RIDERSHIP

One approach for analyzing variations in ridership is to analyze time-series data on transit patronage over a long period of time, 2 to 5 years, for example. Because the data in this case is gathered for a long period of time during which costs and income vary, fare should be examined in real terms; that is, fare should be adjusted by a price index such as the consumer price index. Adjustments for seasonal variations in ridership should be made also because ridership tends to fluctuate according to the time of year in a repeated pattern every year. After appropriate adjustments, the time-series data can be analyzed using the multiple regression technique.

The foregoing approach was adopted by Kemp (*1*) who developed a regression model using data for Atlanta to establish a relationship of transit ridership with fare and the amount of service. The model developed by this study is similar to Kemp's.

Regression Model Variables

Several variables were incorporated into the study to identify their effect on ridership. Each variable investigated for the regression model is discussed in the following sections.

The Dependent Variable

Bus ridership was used as the dependent variable and was defined as the total number of rides or one-way trips that are made in a designated time frame. The ridership data collected from K-TRANS represented the total number of express rides made during a month. The data were obtained by bus drivers by actual count of each person entering the buses. The ridership included a small percentage of nonTVA employees, and, therefore, an adjustment had to be made to obtain estimates of TVA employee ridership. For this purpose, TVA monthly express ticket deposits were divided by monthly express revenue to get the percentage of express revenue contributed by TVA employees each month. This percentage was multiplied by total express bus rides to get TVA employee rides, *RIDES*. To eliminate the influence of seasonal variation on the data, the time series ratio-to-moving average method was used to develop seasonal indices (*2*). Seven years of data, from September 1977 through August 1984, were used for this purpose. The seasonal indices, with a base value of 100, are given in Table 3.

TABLE 3 SEASONAL INDICES FOR TVA EXPRESS BUS RIDERSHIP

Month	Index	Month	Index
January	104.96	July	96.42
February	108.96	August	101.39
March	104.41	September	100.45
April	101.18	October	97.31
May	100.41	November	96.18
June	99.72	December	88.61

As shown by the seasonal indices, TVA ridership is highest in the month of February. This is probably due to inclement weather conditions. Ridership is lowest in December when many TVA employees take annual leave. The seasonally adjusted monthly ridership, *RIDESA*, was determined by dividing *RIDES* by the seasonal index and multiplying by 100. The seasonally adjusted daily ridership, *RIDESAD*, was calculated by dividing *RIDESA* by the number of working days, *DAYS*, in the month. *RIDESAD* is the dependent variable used in the regression model.

Independent Variables

Several independent variables were used in the regression analysis and are described as follows:

1. Bus fare—An inverse relationship between bus fare and ridership is expected. Fares were divided by the urban consumer price index to determine their value of 1972 constant dollars. This variable was labeled *FAREC*.

2. Number of express buses—Labeled *BUSES*, this variable indicated the magnitude of service and is expected to be directly related to ridership. (Each express route provided one inbound trip in the morning and one outbound trip in the afternoon.)

3. Express miles—The mileage covered by express buses per month, *MILES*, was estimated by the transit agency and included deadhead miles. The proportion of deadhead mileage with respect to total mileage remained fairly stable during the analysis period. As with the number of buses, mileage is an indicator of the service level and is expected to be related to ridership. *MILESD* represented the mileage covered per day and was calculated by dividing *MILES* by the number of service days in the month.

4. Knoxville employment—It was expected that TVA's employment and ridership would have a direct relationship because employment is the total pool from which riders are drawn. As the pool declines, the absolute number of rides is also expected to decline. The number of employees, *KNOXEMP*, represents the number of regular TVA employees in the downtown office who were eligible for purchasing the discounted ticket. The variation in the employment level from 1979 to 1984 is given in Table 4.

5. Number of vans—Although TVA has a policy of not assigning vans for vanpooling from areas where express bus services exist, questions have been raised by some concerned individuals and agencies regarding the impact of TVA vans on express bus ridership. The number of vans, *VANS*, represents the total number of vanpools commuting to the Knoxville area during the period. It is expected that the number of vans will adversely affect bus ridership because vanpools provide the convenience of door-to-door service.

TABLE 4 TVA EMPLOYMENT LEVEL IN KNOXVILLE

Year	Quarter	Employment	Year	Quarter	Employment
1979	1	4,478	1982	1	5,370
	2	4,489		2	4,858
	3	4,554		3	4,671
	4	4,624		4	4,578
1980	1	4,711	1983	1	4,591
	2	4,867		2	4,639
	3	5,067		3	4,673
	4	5,198		4	4,671
1981	1	5,315	1984	1	4,657
	2	5,298		2	4,621
	3	5,324		3	4,531
	4	5,408			

6. Inches of snow—Although transit ridership was adjusted for seasonal variation, climatological data were collected for Knoxville to find out whether unusual variations in snowfall had an additional influence on ridership. It is believed that the number of inches of snow, *SNOWIN*, has a direct influence on bus ridership because many people who normally use cars or vans switch to buses on these days.

7. Trailways and bus fare—Trailways, a private company, operated an express bus route in an area in close proximity to K-TRANS express service in west Knoxville. In August 1980, Trailways doubled its fares 1 month after K-TRANS raised its fares. Ridership on K-TRANS buses increased during this period. Therefore, the fare data from the alternative bus service, *TRAIL*, was incorporated into the model. *TRAIL* was divided by *CPIU* to represent fares in real terms, *TRAILC*. It was expected that *TRAILC* would directly influence K-TRANS ridership.

8. Highway construction—A dummy variable was used to represent highway construction during the period of January 1980 through April 1982. There were considerable construction activities during that period and an inverse relationship between highway construction, *HWY*, and transit ridership is expected because of increased travel time for buses during this period. Buses were less flexible than cars and vans in altering routes to avoid congested areas during construction.

9. World's fair—A dummy variable, *EXPO*, was inserted to represent the 6-month period from May 1982 through October 1982 when the World's Fair was held in Knoxville. Bus ridership is expected to be directly related to *EXPO* because of increased congestion and parking costs in the central business district (CBD) during this period.

Variable Relationship and Significance

A least-squares regression analysis including all independent variables discussed in the previous section was performed using the SAS Institute's (Cary, North Carolina) computer software package. The number of cases (the number of values of the dependent variable) used in the regression analysis was 68. The relationship of each independent variable with the dependent variable, whether or not any was significant at the 95 and 99 percent confidence levels, is given in Table 5.

The nature of relationship of all variables with respect to ridership, the dependent variable, was as expected. The only variables that were significant in the model were *FAREC*, *MILESD*, *BUSES*, and *KNOXEMP*. It should be noted that *MILESD* and *BUSES* were correlated with each other, and, therefore, both variables could not be included in the model at the same time. *MILESD* was chosen over *BUSES* because it more accurately represents the magnitude of service.

Note that the relationship of service miles with ridership is usually fairly clear in the case of a regular fixed-route transit service because service miles represent opportunities for using the service. In the case of TVA's express bus service, however, the relationship between these two variables was not exactly similar for several reasons. The express service had ample

TABLE 5 RELATIONSHIP AND SIGNIFICANCE OF VARIABLES

Independent Variable	Relationship with Ridership	Significant at 99%	Significant at 95%
FAREC	Inversely	Yes	Yes
MILESD	Directly	Yes	Yes
BUSES	Directly	Yes	Yes
KNOXEMP	Directly	Yes	Yes
VANS	Inversely	No	No
SNOWIN	Directly	No	No
TRAILC	Directly	No	No
HWY	Inversely	No	No
EXPO	Directly	No	No

opportunities for park-and-ride, and in some cases park-and-ride lots were served by multiple express routes. Thus the elimination of one express route did not necessarily remove all opportunities for riders to use express buses. Efforts were also made to capture some of the riders of discontinued routes by modifying the routing of other express buses.

Stepwise Regression

Stepwise regression was used to determine the best of one-, two-, three-, and four-variable models.

1. Single-variable model—The best single-variable model was with the independent variable *MILESD*, which yielded the following equation:

$$RIDESAD = -739 + 2.55\ MILESD$$

The R-square value for this model is 0.901. It may be noted from the correlation matrix in Table 3 that the simple correlation coefficient (R) for the two variables *FAREC* and *RIDESAD* is −0.74854, which yields an R-square value of 0.56. Thus, a single-variable model, with *FAREC* as the only independent variable, would not have the explanatory ability of one with *MILESD*.

2. Two-variable model—*FAREC* and *MILESD* were the two variables selected for this model. The equation is

$$RIDE = -280 - 1088.74\ FAREC + 2.21\ MILESD$$

The R-square value for this equation is 0.919.

3. Three-variable model—The best three-variable combination included the variables *FAREC*, *MILESD*, and *KNOXEMP* and yielded the following equation:

$$RIDESAD = -623 - 1709.64\ FAREC + 1.80\ MILESD + 0.15\ KNOXEMP$$

The R-square value for this equation is 0.932.

4. Four-variable model—The best four-variable combination included the variables *FAREC*, *MILESD*, *KNOXEMP*, and *VANS*, the resulting equation being

$$RIDESAD = -640 - 1404.62\ FAREC + 1.65\ MILESD + 0.20\ KNOXEMP - 2.42\ VANS$$

The R-square value for this model is 0.936.

Coefficient Stability

The coefficients in each of the models developed by the stepwise regression remained stable as variables were added. The following equations illustrate this:

1. $RIDESAD = -739 + 2.55\ MILESD$,
2. $RIDESAD = -280 - 1088.74\ FAREC + 2.21\ MILESD$,
3. $RIDESAD = -623 - 1709.64\ FAREC + 1.80\ MILESD + 0.15\ KNOXEMP$, and
4. $RIDESAD = -640 - 1404.62\ FAREC + 1.65\ MILESD + 0.20\ KNOXEMP - 2.42\ VANS$

As a new variable is added, the previous variable or variables selected remained significant and stable. This demonstrates that the model is rigorous. Also, no problem of multicollinearity between the independent variables appears to exist. To examine this further, the correlation matrix is analyzed.

Correlation Matrix

The correlation matrix given in Table 6 includes the significant independent variables and shows their correlation with the dependent variable and with each other. The relationship of the independent variables to each other does not show any strong correlations between any two variables. Therefore, there appears to be no problems of multicollinearity among independent variables.

TABLE 6 SIMPLE CORRELATION MATRIX

Variable	*RIDESAD*	*FAREC*	*KNOXEMP*	*MILESD*
RIDESAD	1.00000	−0.74854	0.48944	0.94915
FAREC	−0.74854	1.00000	0.01305	−0.68456
KNOXEMP	0.48944	0.01305	1.00000	0.49912
MILESD	0.94915	−0.68456	0.49912	1.00000

Prediction Accuracy of the Selected Model

The model selected for this study is the three-variable model represented as follows:

$$RIDESAD = -623 - 1709.64\ FAREC + 1.80\ MILESD + 0.15\ KNOXEMP$$

This model was selected because all three variables are significant at the 99 percent confidence level. Furthermore, from the conceptual standpoint, the three independent variables complemented each other. *FAREC*, of course, is an important variable because its effect on changes of ridership is of major interest for this investigation. However, because *RIDESAD*, the dependent variable, is an aggregate measure of ridership, there is a need for an independent variable of aggregate nature reflecting the magnitude of service; *MILESD* served this purpose well. The independent variable *KNOXEMP* may be viewed as representing the density of TVA employees served by the express routes.

The difference between actual ridership and predicted ridership resulting from this model is shown in Figure 1. A particular case for which the application of the model would have been useful in predicting the impact of a fare change is discussed next.

In October 1981, the fare was increased from \$0.585 per ride to \$0.845 per ride. The CPIU for converting the 1981 fare to 1972 dollars is 2.799. In the preceding month of September, the seasonally adjusted actual ridership level was 1,048 and the number of miles per day that the buses traveled was 708. TVA employment level in Knoxville at the time was 5,342. If the transit manager planned to maintain a constant service level and expected the employment level to remain stable, the ridership level for October could have been predicted with the model as follows:

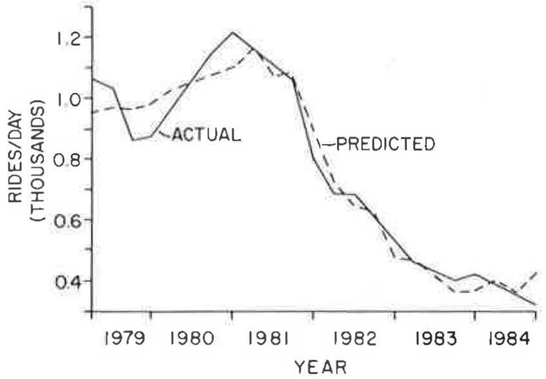

FIGURE 1 Actual ridership versus predicted ridership.

$$RIDESAD = -623 - 1709.64(0.845/2.799) + 1.80(708) + 0.15(5342) = 936.57$$

Because *RIDESAD* represents a seasonally adjusted figure, the actual ridership figure to be used for comparison should also be adjusted for seasonal variations. The actual seasonally adjusted ridership for October 1981 was 847.48, which is 89 rides less than the predicted number. This represents approximately a 10 percent error in estimation.

With reference to the situation in the preceding month of September, the model would have predicted a decrease in ridership by 10.6 percent accompanied with an increase in revenue of 29.1 percent. In actuality the ridership dropped by 19.1 percent and revenue increased by 16.7 percent.

ELASTICITY MEASURES

An alternative way to analyze changes in ridership is through elasticity measures. An elasticity measure, *E*, can indicate to transit managers how much influence a particular factor has on the ridership level. With reference to fare, the elasticity of demand is defined as the ratio of the percentage change in ridership to the percentage change in fare. In mathematical terms, this is expressed as

$$E = (dQ/Q)/(dF/F)$$

or,

$$E = (dQ/dF) \times (F/Q)$$

where E is the point elasticity of demand defined at the ridership level Q and the fare level F. In the formula, dQ and dF represent the derivatives (or incremental changes) of the respective variables—ridership and fare. The concept of point elasticity is difficult to apply to practical cases unless the changes in ridership (Q) and fare (F) are very small. In most cases, therefore, the concept of arc elasticity is used, which permits the use of average values of ridership (Q) and fare (F) based on their levels before and after a change occurs.

The elasticity measurement just discussed estimates the percent change in ridership for every 1 percent change in fare. A similar approach can be used to analyze relationships between ridership and other parameters also, such as service and employment levels.

In order to measure elasticity, an attempt must be made by the analyst to describe the response of a trip maker to a change in one factor at a time by holding other factors constant. The regression model presented in the earlier section can be used for this purpose.

Elasticity Coefficients

The regression model derived a coefficient, b_i, to describe the influence of each variable in the model. For each variable an elasticity measure can be derived if it is assumed that the other variables of the model remain constant. For example, to determine an elasticity measure for *FAREC* (F) from the regression model, it may be assumed that *MILESD* (M) and *KNOXEMP* (K) remain constant. The regression equation for estimating *RIDESAD* (Q) can be expressed in the following forms:

$$Q = a + b_F F + b_M M + b_K K$$

Therefore

$$dQ = b_F(dF) + b_M(dm) + b_K(dK)$$

If dM, the change in *MILESD*, and dK, the change in *KNOXEMP*, equal zero, then

$$dQ = b_F(dF)$$

or,

$$b_F = dQ/dF$$

By definition, fare elasticity is equal to

$E_F = (dQ/dF) \times (F/Q)$

Substituting b_F for (dQ/dF)

$E_F = b_F \times (F/Q)$

In the case of this analysis, the regression equation was developed using time-series data on each variable. The fare was adjusted based on urban consumer price index, and ridership also was adjusted to eliminate the effect of seasonal variations. Thus, the coefficients reflected the changes occurring during the analysis period, and the concept of arc elasticity is applicable to this case. Using the mean values of F (*FAREC*) and Q (*RIDESAD*) during the analysis period, as well as the regression coefficient of F (*FAREC*):

$E_F = -1709.64(0.2356143)/771.56 = -0.522$

The standard deviation was calculated using the t-value for the 99 percent confidence level at 64 degrees of freedom. Based on the standard error of $b_F = 315.96$:

$E_F = -0.522 \pm 0.257$

The elasticity measure and standard deviation for the other variables are as follows:

Elasticity coefficient for *MILESD*

$E_M = 1.8(591.146)/771.56 = 1.38$

Based on the standard error of $b_M = 0.1676$

$E_M = 1.38 \pm 0.34$

Elasticity coefficient for *KNOXEMP*

$E_K = 0.15(4839)/771.56 = 0.941$

Based on the standard error of $b_K = 0.043$

$E_K = 0.941 \pm 0.716$

Assessment of the Fare Elasticity Measure

In the past, the Simpson and Curtin (consulting firm) formula has been used widely in the transit industry for predicting the impact for fare changes. The formula predicts that transit ridership will increase (decrease) 0.3 percent for every 1 percent decrease (increase) in fare over their previous level (*3*). However, this rule of thumb may not pertain to every case because of differing elasticity measurements. Reasons for the differences are described in the following examples.

City Size

Small cities have higher fare elasticities than large cities. This is because small cities usually have less congested central business districts (CBDs) and lower parking costs. The mean all-hour fare elasticities for central cities of different sizes have been estimated for the following central city populations (*4*):

- Greater than 1 million—$E_F = -0.24 \pm 0.10$
- 500,000 to 1 million—$E_F = -0.30 \pm 0.12$
- Less than 500,000—$E_F = -0.35 \pm 0.12$

The city of Knoxville has a population of nearly 175,000 with the population of the metropolitan area being approximately 250,000. The CBD does not experience serious traffic congestion during rush hours. Monthly parking is available at prices ranging from $20 to $40.

In another analysis based on 28 cases, the aggregate fare elasticity and its standard deviation were estimated as −0.42 ± 0.24. These 28 cases included data from large cities such as New York, Chicago, Atlanta, and San Diego, and the data are for all hours of the day (*4*).

Peak Versus Off-Peak Travel

Most peak-hour trips are routine work trips; therefore, it is generally believed that peak-period travel is less responsive to fare changes. In almost every study where peak and off-peak fare elasticities have been estimated, off-peak elasticities are two to three times larger than peak travel (*4*). In a recent study of a 10 cents fare increase for the bus system in Mercer County in the Trenton, New Jersey, area, the fare elasticity of commuter travel was found to be −0.15, whereas that for noncommuter travel was −0.29 (*5*). The express buses in Knoxville catered to work trips during peak hours.

Captive and Choice Riders

Passengers who have an alternative mode of transportation are more responsive to fare changes than others and, therefore, they have a more elastic response to a fare change. Many of the express bus riders in Knoxville are choice riders. This is evidenced by the fact that many riders drive to park-and-ride lots to catch the buses.

Income Group

People in higher income groups may be expected to have larger fare elasticities than those of lower income groups. The majority of express bus riders in Knoxville earn incomes greater than $15,000 per year.

Comparison of Fare Elasticity

The fare elasticity measure developed in this study for K-TRANS express buses is −0.522 ± 0.257 for TVA employees. This indicates that for every 1 percent change in fare, ridership will vary inversely by 0.522 percent. This value is higher than elasticity values developed in other areas. The larger elasticity value for the Knoxville area may be attributed to its smaller size, choice riders, an uncongested CBD with reasonable parking costs, and flexible working hours for TVA employees.

Assessment of the Service Elasticity Measure

The K-TRANS express bus service, as measured in terms of vehicle miles of travel by the buses, declined by 39 percent between November 1981 and June 1983. The number of buses (or bus routes) declined from 17 to 10 during this 18-month period. When a route was eliminated, an attempt was made to capture some of the former riders by adjusting and extending the existing routes. This resulted in longer travel times for many of the remaining routes. The estimated elasticity measure of 1.38 shows ridership to be elastic with respect to service cuts. This relatively high elasticity value may have resulted because of service cuts in vehicle miles, as well as increased travel times on the remaining routes. A few other studies investigated service elasticities resulting from expansions. Kemp analyzed time-series data for San Diego where service was expanded substantially over a 40-month period and found the elasticity to vary between 0.75 and 0.85 (*6*). In Atlanta, where service expansion occurred over a much shorter time period, Kemp estimated an elasticity with respect to vehicle miles of service of 0.30 (*1*).

SUMMARY AND CONCLUSION

The least-squares regression model derived to explain the variation in TVA employee ridership on K-TRANS express buses is

$$\mathit{RIDESAD} = -623 - 1709.64\ \mathit{FAREC} + 1.80\ \mathit{MILESD} + 0.15\ \mathit{KNOXEMP}$$

The R-square value for this equation is 0.932. All variables selected for this model are significant at the 99 percent confidence level. This model would be useful in predicting ridership changes and resulting revenue changes when fares or TVA employment in Knoxville change.

The demand elasticity measures (and standard deviation) with respect to each variable of the model are

$$E_F = -0.522 \pm 0.257$$
$$E_M = 1.38 \pm 0.34$$
$$E_K = 0.948 \pm 0.716$$

The elasticity measure for *FAREC* is slightly higher than those found in other studies. The elasticity coefficient for *MILESD* is considerably higher than those for other studies. No comparison was made for the elasticity with respect to employment.

It should be pointed out that the regression model and demand elasticities derived by this study may not be applicable to all cases of express bus service for commuters. The characteristics of TVA employees using the service, the size of the Knoxville urban area, and TVA's rideshare program for its employees are examples of background conditions that must be taken into consideration before deciding to transfer these results to another case.

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Overseas Applications of Microcomputers on a Transportation Planning and Engineering Design Project

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The application of microcomputers in various phases of a multidisciplinary project encompassing a comprehensive transportation planning study and preliminary engineering for a metro or rail rapid transit system and an underwater railroad tube tunnel for Istanbul, Turkey, is described. Microcomputers were used to process the results of a 9 person-year effort of travel data collection. Over 70 megabytes of processed data files were created using various specialized software programs. Calibration of a complex four-step transportation modeling system, as well as testing of numerous alternatives were successfully accomplished on microcomputers. A wide range of engineering applications, structural analyses, cost estimation, project control and scheduling, and cost control tasks also were accomplished for which the microcomputer was found to be an indispensable tool. Tabulations of data and results, computer-generated graphics, and the word processing capabilities of microcomputers permitted the efficient production of a large number of complex project reports (in two languages) on time and in a cost-effective manner. Staff training of personnel without previous computer experience was surprisingly easy and was accomplished within a very short period of time due to the user friendliness of modern software. The versatility of microcomputers and the effectiveness with which they were applied to this complex overseas project was surprising. Despite certain difficulties and problems, it is apparent that present day microcomputer technology can be successfully used in somewhat isolated overseas environments to develop a complex engineering/planning project.

The use of microcomputers on various phases of a multidisciplinary project in Istanbul, Turkey, is described. The project encompassed a comprehensive transportation planning study, as well as preliminary engineering for a metro or rail rapid transit system and an underwater railroad tube tunnel across the Bosphorus Strait. Advantages found in using microcomputers on the project are discussed along with problems encountered and lessons learned.

Computer technology has advanced rapidly with the recent introduction of fast and high-capacity microcomputers. This advancement, particularly with the PC-DOS family of microcomputers, coupled with the recent developments in transportation planning, engineering, and data-handling software designed for this family of machines, has led to very efficient, cost-effective, and user-friendly desk top computer power. Therefore, it was decided early in the planning of the Istanbul project that extensive use would be made of microcomputers.

IBM/XT and COMPAQ microcomputers were used to perform various tasks for the wide range of planning and engineering disciplines required for the Istanbul project. An IBM/AT was used to calibrate a four-step transportation modeling system, as well as to test the alternative transportation improvements being considered.

Over seven million pieces of information from a 9 person-year travel data collection effort were processed; the microcomputers were used to tabulate post-model run results and make graphics; to run and tabulate the results of cost estimation models; to perform economic and financial analyses of alternatives; and to carry out engineering analyses and data handling for extensive use as word processors for the heavy volume of report production in both Turkish and English. The microcomputers were also used for project cash flow and cost control and for various other project management tasks.

Seven microcomputers were used, including an IBM/AT; two IBM/XTs; two COMPAQ/plus (with 10-megabyte hard disk drive capacity) imported from the United States to Turkey; and two additional double floppy disk drive model COMPAQs obtained locally.

MICROCOMPUTER APPLICATIONS ON THE ISTANBUL PROJECT

Some of the applications of the microcomputer on the Istanbul project are described, particularly those relating to the transportation planning aspects of the project.

Travel Data Processing and Analysis

Sixteen different travel surveys and counting programs generated over 165,000 records with 209 types of data. An initial search of data collection and marketing research companies in the Istanbul region to carry out the surveys indicated that there were few qualified firms to choose from. All but one of the firms were either too small in size or were specialized in areas of market research that would not be applicable to the work needed for this study. The travel surveys were all conducted by this one firm under the supervision of the project staff. Data entry keypunching was also subcontracted to a local computer

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firm. All of the records in a data base were verified and checked thoroughly by the project staff. As each data base was corrected, it was converted to PC-File format (a general file-handling and data-base management program), and the diskettes were delivered to the planning and feasibility staff. The local firm for travel surveys and data entry completed their responsibilities satisfactorily and the subsequent work was accomplished in-house by the project staff.

The raw data had to be sorted by station/location, day of survey, and direction using the PC-File program. The classified PC-Files were then converted into ASCII files to be processed using SYSTAT, a general purpose statistical program. The SYSTAT package was used to tabulate trip volumes by station, day, direction, time of day, and type of vehicle. Vehicle volumes were tabulated and the average vehicle occupancies derived from the survey were applied to yield person trips by mode of transportation. A stratified small sample home interview survey was also analyzed using the SYSTAT program.

Transportation Modeling System Calibration and Application

A four-step transportation modeling system (trip generation, trip distribution, mode choice, and trip assignment) was calibrated running the model on IBM/XT and IBM/AT microcomputers. TRANPLAN was used for the trip distribution and trip assignment steps in the model, while separate programs were developed for the trip generation and mode choice models. Findings from the model calibration efforts showed that the modeling system performed remarkably well because the estimated number of total person trips compared closely to their respective observed values at different screenline locations. In addition, the estimated number of automobile and transit trips were also comparable to their respective observed values. In carrying out this work, the data plotting capabilities of the microcomputers was of great help when comparing estimated values with observed values and presenting results to the client.

The modeling system has been used to test and evaluate several transportation alternatives including a metro system, light-rail transit, commuter railroad improvements, express bus routes on exclusive busways, conventional local bus service improvement and shared taxi operations, ferry boat system improvements, and a railroad tunnel beneath the Bosphorus connecting the Asian and European sides of Istanbul.

Testing of the alternatives was carried out entirely on the IBM/AT in the project office. A complete overall modeling system run, including network building, trip distribution, mode choice, and trip assignments of automobile and transit person trips, took less than 2.5 hr. The model results, capital/operating cost estimates, and economic evaluation of alternatives were tabulated or analyzed using SYMPHONY.

Highway link and transit link/line data files were created using the IBM editor program. Various TRANPLAN programs were run on both IBM/XT and IBM/AT microcomputers and the run time comparisons for a 107-zone system (with 1,835 highway and 1,544 transit links) are given as follows. The advantage of the newer, faster technology of the IBM/AT computer over the earlier PC/XT series is clearly shown.

	Run Time (min.)	
Program Name	*IBM/XT*	*IBM/AT*
Build highway network	5.5	1.5
Build highway skim table	10.0	4.0
Gravity model	25.0	8.0
Create origin-destination (O-D) trip table	3.0	1.5
Load person trips to highway network	12.0	2.0
Overall TRANPLAN-related steps of model system (107 zones with 1,835 highway and 1,544 transit links)	57.5	19.0

Engineering-Related and General Purpose

The engineering design group used microcomputers to perform a wide range of different tasks related to the project. The structural group carried out a finite-element analysis, an analysis of wall and pile designs using special purposes structural software written in FORTRAN, and various drawing/plotting programs such as AUTOCAD and PLOTTRACK. The civil and alignment group used COGO and similar programs for the geometric design/analysis of guideways and roadways. The cost estimating groups primarily used SYMPHONY for cost spreadsheets.

The project included an intensive study of the hydraulic characteristic of the Bosphorus waterway. The group doing this work collected meteorological, tidal, current, salinity, density, conductivity, and temperature data. SYMPHONY, GRAPHS, AUTOCAD PENPAD (for digitizing), and specialized programs written in BASIC were used to process, analyze and plot data. The geological and geotechnical group used SYMPHONY to tabulate and analyze data for an extensive subsurface investigation program.

Finally, the project involved the production of an extraordinary volume of reports, contract documents for subcontractors, handouts for presentations to various government agencies and many other documents, in both English and Turkish. This was a major undertaking almost exclusively accomplished on the microcomputers throughout the office using VOLKSWRITER DELUXE. It was decided early on not to invest in dedicated word processors but to utilize the compatibility of the various PC DOS computers so that any of the office units could be used. Two microcomputers were assigned to a word processing department, but virtually everyone in the office mastered word processing quickly so that the work could be done on any available machine.

As can be seen from the foregoing discussion, microcomputers were used to produce reports, graphics, plots, and displays for both analytical and presentation purposes in all the disciplines. In addition, microcomputers enabled staff to be trained in the uses of both general purpose and task-specific software. The training of young Turkish engineers in state-of-the-art computer usage was a significant benefit to the host country as well.

MICROCOMPUTER HARDWARE AND SOFTWARE

Hardware

Various models of compatible microcomputers were used, based on the DOS operating system. Printers, plotters, and back-up units have been used also (Table 1).

Software

The software purchased for this project is listed as follows:

Software Purchased	*Function*
PC-FILE and dBASE III	For coding of survey results and initial sorting of raw data
SYSTAT	A general purpose statistical analysis program for travel/home interview surveys and counts, statistical analysis, and estimation of mode choice model parameters
SYMPHONY	Spreadsheet program for data tabulations, summaries, graphing, and word processing
TRANPLAN	The transportation modeling system used for network building, trip distribution, application of the mode choice model, and automobile/transit trips assignment
AUTOCAD, PENPAD, and PLOTTRACK	Used for digitizing and plotting graphs
VOLKSWRITER DELUXE	Word processing
COGO and SIMILAR	Programs used for geometric design/analysis and alignment studies for railroads and roads
MICROSOFT FORTRAN compiler	Used for FORTRAN programming
IBM professional editor	Used for data entry and editing

Programming languages include:

- FORTRAN—Used in finite element analysis of structural members and to estimate modal shares outside TRANPLAN using a binary logic model framework. Programs were also written by planning and engineering staff to complement available software programs for specific tasks.
- BASIC—General purpose programming language.

ADVANTAGES OF MICROCOMPUTERS

The following paragraphs address the various advantages revealed when using microcomputers for the Istanbul project.

Speed, Capacity, and Ease of Implementation

It was found that the direct hands-on access to the microcomputer, the ease of learning the microcomputer systems, and the availability of existing software permitted a much larger portion of the available professional time to be spent in creative discussion and analysis. The elimination of the need for Job Control Language (JCL), which is frequently needed when using a mainframe computer, simplified both the programming and the running of the programs.

For example, it took approximately 3 months to process and tabulate the transportation-related raw survey data. The data processed for the statistical analysis and tabulation graphics generated over 70 megabytes of microcomputer-related files. The calibration of a four-step transportation modeling system was successfully accomplished in approximately 3 months. The data processing efforts were achieved by using only IBM/XTs and COMPAQs, and the files were backed up onto a magnetic tape unit (TALLGRASS Model 4060).

Microcomputer capability in computational and reporting tasks is unique because the planner or engineer has instant access to a desktop unit providing direct control of the work. Programs written for microcomputers are usually designed to be user friendly, and personnel can be trained in their use in a short period of time. The ease of access and control of the microcomputer makes it possible for the professional to spend time more efficiently and productively. By proper scheduling of time and machine use, the microcomputer can be loaded for tasks such as data sorting or model runs, while the user is working on other tasks, or even during the lunch break.

Use of microcomputers has resulted in a change in required staff qualifications. Previously, much of the data processing was done by technicians. For example, on the planning study for the Caracas Metro, which one of the authors of this paper directed from 1966 to 1969, it was necessary to send a small team of analysts back to the United States where computer facilities and staff were available to operate the transit ridership forecasting models. The hands-on interactive nature of the

TABLE 1 LIST OF MICROCOMPUTER HARDWARE USED IN ISTANBUL METRO RAIL/TUNNEL PROJECT

Computer Type	Printer Type	Plotter Type	Back-Up Unit Type
COMPAQ/Portable	OKIDATA-92	–	–
COMPAQ/Portable	OKIDATA-92	–	–
COMPAQ/Plus	FX-100	HP-7475	TALLGRASS-4060
COMPAQ/Plus	OKIDATA-82	–	–
IBM/XT	OKIDATA-93	PENPAD	–
IBM/XT	OKIDATA-93	MOUSE SYSTEMS	–
IBM/AT	OKIDATA-2410	–	TALLGRASS-4060

microcomputer permits direct involvement of project staff, which is very cost effective. By avoiding the time lost when waiting for data to be processed on a mainframe in another office, and having answers in minutes rather than days, costly professional time (particularly in the case of U.S. personnel being maintained overseas) was saved almost daily for the Istanbul project.

The use of the microcomputer for word processing on a project where two (or more) languages are involved provides a substantial saving in professional time used for editing and correction. On this project, the PC-DOS computers could be patched with a simple keystroke to convert to the Turkish alphabet.

The wide-ranging library of engineering software now available to the engineer equipped with the PC-DOS microcomputers is well known. Even for the preliminary sections of the engineering designs undertaken on this project, substantial use was made of the microcomputer for structural and tunneling analyses. The wide-ranging versatility of the microcomputer included other important uses for cost control scheduling, cash flow analyses, and personnel and office management tasks. On the latter applications, it can be said that the microcomputer paid for itself.

Comparison of Microcomputer and Mainframe Utility

A mainframe computer is clearly capable of performing most of the functions for which the microcomputers were used in this project. The advantages of the microcomputer include:

- Fast turn-around time,
- Ease of learning,
- Direct access,
- Cost effectiveness,
- Multipurpose uses such as word processing, and data handling/analysis, and
- Direct control of work by the professionals on a real-time basis.

Although the memory capacity of the microcomputer may currently limit its application for very large and complex systems, the rapid advancement of the state of the art in microcomputer technology with the introduction of faster and more powerful systems and software is resulting in the use of microcomputers for larger and larger undertakings. The benefits of microcomputer use in planning and engineering projects were revealed by their use in the Istanbul project.

PROBLEMS ENCOUNTERED AND LESSONS LEARNED

Problems with the installation and operation of computer facilities in a developing country posed some interesting challenges. For the benefit of others interested in similar applications, some of these are described in the following section.

Hardware Import and Installation and Supplies

Initial investigations regarding procurement of microcomputers indicated that the local firms could not deliver all the necessary equipment in less than 90 days. In addition, the initial cost savings, resulting from differences in microcomputer costs, convinced the project management that most of the equipment should be purchased in the United States. The hardware items listed previously were imported in early May 1985, and the import duties were waived conditionally on reexportation of all the equipment at the end of the project. The shipment of IBM/AT was delayed until June 1985 pending issuance of an export certificate by the U.S. Commerce Department. The IBM/AT had not yet been introduced on the local market.

The release of hardware items from customs (except the IBM/AT) took over 1 month because of the lack of advance knowledge on the part of project management of the various government regulations. The release of the IBM/AT was delayed much longer, until mid-September 1985, for similar reasons and extra requirements related to the IBM/AT. The unit was the first microcomputer of its kind to be exported to Turkey, and, at the time the U.S. government expressed concerns relating to the exportation of high-technology computers. Procurement of necessary supplies and parts and maintenance services for the microcomputers was not free of problems either. COMPAQ had no representation in Istanbul and all of the local IBM representatives were found to be European-based affiliates. Because of this they did not wish to provide maintenance services other than to clients who had purchased computers locally. This situation was rather burdensome at times in terms of maintaining the equipment. Eventually, some maintenance services were secured from a local firm.

In the process of installing the IBM/AT microcomputer, running the diagnostic tests, and trying to install the software programs, the following problems were detected by the local service personnel:

1. The math coprocessor, which had been purchased for the IBM/AT, had neither been installed in the AT nor shipped with it for installation. This was vital for the efficient running of TRANPLAN programs.
2. The AT was equipped with a 20-megabyte hard disk drive and one high-capacity floppy disk drive. A 360K double-sided floppy disk drive compatible to the AT should also have been installed in the machine in order to easily transfer data between the AT and the XTs and the COMPAQs in the office. The second disk drive had been specified during the process of ordering the IBM/AT from the United States, but the message was missed somewhere. This second drive had to be imported and added later.
3. The high-density floppy disk drive was not functioning properly. It inconsistently read floppy disks placed in the drive. The local firm suggested the need for Adjustable Diagnostic Test diskettes to readjust the high-density disk drive. Such software was not locally available and had to be brought to the project by a traveler.
4. Initially, the TALLGRASS units were inoperable with the AT. Both units functioned properly with both XTs. This prob-

lem was critical because files that were supposed to be created on the AT could not be backed up and the 70 megabytes of processed data could not be retrieved for use on the AT. It was realized later that an updated version of TALLGRASS software was needed to interface with the AT instead of the existing software. A search was conducted for 2 weeks in the United States until a member of the project staff was informed by a friend from California that a local IBM representative in the Istanbul area could provide the software.

Hard Disk Failure

The hard disk installed in the IBM/AT failed in mid-November 1985 during a critical period of calibrating the transportation modeling system. The local service representative determined after 2 days of examining the hardware and operating system that the hard disk needed replacement. The hard disk was not available in the local market. The AT was still within the warranty period, but the original AT seller in the United States could not supply the replacement in a reasonable time. Consequently, an AT machine in the consultants' New York office had to be taken apart to obtain a hard disk unit that could be shipped to Istanbul. The entire process took approximately 3 weeks before the AT became operational again. In the meantime the model calibration efforts were continued using the XT, but with much slower operation.

Power Incompatibility

Because Istanbul uses 220-V 50-cycle alternating current (AC), power outlets needed to be made compatible with the 110-V 60-cycle AC imported microcomputers. Transformers were installed in the office before machines arrived. Unfortunately, the transformers had to be replaced because they were found to be inadequate in handling the total requirements of the computers, together with their accessories such as the units and the larger-sized printers. The project management had decided to import an uninterruptable power supply (UPS) back-up unit in case the electrical power was disrupted during a critical model run. Local electrical firms could not supply such a unit and it had to be imported. The order went out in June 1985. When it finally arrived in October, the prevailing local import/export formalities had to be accomplished again for its release from customs. This resulted in several more weeks of delays. When the UPS finally arrived in the project office, it was discovered that its electrical requirements were incompatible, in almost all respects, to the local current. Fortunately, the local power reliability turned out to be satisfactory and the power disruptions were limited to occasional electrical transients. External surge protectors were installed for all the microcomputers in the office, and two had to be replaced due to accidental use of wrong voltage outlets (220 V instead of 110 V).

Accessibility to Software Developers

The project's planning and feasibility study staff faced software problems on several occasions during the data processing and model calibration efforts: questions had to be communicated at long distance to the firms in the United States that had developed the software programs.

The lack of direct access to the developer of the software because of distance (inaccessibility to user hotlines) for immediate resolution of problems is an important factor when considering the use of sophisticated software overseas. Work schedules and contingency plans should be made accordingly. It was found that software on diskettes must be shipped in special X-ray resistant bags for protection against the X-ray devices at airports. In one case, before the introduction of the protective bag, several diskettes were damaged in transit, possibly by X-rays.

Data Storage Limitations and File Handling/Back-Up Procedures

Because of the storage limitations of individual microcomputers, proper use of the machines for general purpose and specific tasks should be taken into consideration.

Files were backed up on a regular basis, initially onto diskettes and later onto a TALLGRASS technology tape cassette (with over 55 megabytes capacity per cassette). The purpose of this was to clear both hard disk memory space and floppy diskettes (if necessary) for efficiency of operation and creation of new files.

It was decided that two copies of each file should always be available. A working copy of each file was kept in a safe located in the office, and a second copy (stored either on tapes or diskettes) was kept in a safe deposit box in a bank nearby.

The importance of a back-up device, such as the TALLGRASS unit, was not fully realized until the staff completed the overall data processing activities, which generated over 70 megabytes of processed data files. The files were copied onto tapes on a daily basis as the work progressed. The staff was forced to do this because of the memory space limitation of the XT and the AT. Had the tape unit not been available, the number of diskettes required for clearing the hard disk space and providing the back-up files would have resulted in a very costly and inefficient operation.

Staff Training and Management of Microcomputer Time

The need for staff training was realized long before the arrival of the microcomputers in the office. In the weeks following the arrival of the equipment, introductory seminars were held in the office on microcomputer operation. The seminars had enthusiastic participation of the staff at all levels. Thereafter, the management of time on the microcomputers became very important as the demand for their use by staff increased. Staff members were encouraged to stay late in the afternoons or occasionally spend the weekends to get familiarized with microcomputer operation. The staff quickly learned this by using the general purpose software programs such as SYMPHONY or VOLKSWRITER. Different departments developed skills in using more specific software programs such as TRANPLAN and finite element analysis. Training for the use of these programs was provided by the responsible technical staff in each department. Software user manuals were prepared by the senior staff directly involved in each technical task. The importance of documentation detailing the file archiving/retrieval and system operations should not be underestimated.

After the various expatriate specialists and senior staff completed their assignments and returned to the United States, the local staff had to be able to fully use the computerized systems developed during the course of the project. Consequently, the need for the training of the local personnel, as well as the preparation of adequate documentation, were of great importance. It was learned that the most efficient way of satisfying these needs was through active participation of the local staff at all levels in the uses of various software programs and their involvement in the corresponding documentation on a daily basis.

CONCLUSIONS

The use of microcomputers on this project in Turkey can be considered a success. In spite of the problems involved in importing, obtaining, and maintaining these facilities, the project goals were accomplished efficiently through use of microcomputers. An added side benefit was provided to the host country in the training of local engineers in a variety of microcomputer applications.

In undertaking a program of microcomputer utilization in a third world country with limited local resources, stringent importation restrictions and untrained local personnel, a number of considerations should be kept in mind:

1. Knowledgeable personnel in the United States must specify well in advance the amounts and types of hardware and software needed for the anticipated tasks.
2. Personnel should be provided in the overseas office who are well acquainted with the importation documentation and paperwork necessary to enter the required equipment into the country in a timely and cost-effective manner.
3. With overseas government clients for whose projects customs duties can usually be waived or sidestepped, it is usually cost effective to buy the equipment and software in the United States because the locally available equivalents usually carry heavy import duties already included in the price.
4. Time must be allowed and training provided for updating the local staff on procedures.
5. Local electrical parameters, such as voltage, frequency, voltage regulation, outages, and so on, must be planned for during selection of equipment.
6. Access to software originators, particularly for uncommon packages, must be available to avoid delays to the work.
7. Consideration must be given to file back up methods as in any endeavor of this kind, particularly when relatively untrained personnel must process costly software and data files.
8. When a great deal of report text must be developed (in this case, in two languages), it is a major benefit if word processing, together with several copies of the same program, can be made available to all personnel using compatible computers (not dedicated word processors). On this project, VOLKSWRITER DELUXE was chosen because of its simplicity and the fact that everyone could learn its use very quickly.
9. An interesting effect was noted: No matter how many computers became available during the early days of the project, they were always found to be fully occupied. Computer time management was quickly found to be a vital consideration.
10. Ample spare parts, extra diskettes, must be purchased from the start.

Finally, the versatility of microcomputers and the ease and effectiveness with which they were applied to this complex project overseas was most satisfying. The rapid advancement of the state of the art in microcomputer technology is enabling planners and engineers to manage ever more efficient, timely and cost-effective operations both at home and in overseas environments.

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Extensions of Stochastic Multipath Trip Assignment to Transit Networks

ALAN J. HOROWITZ

A procedure for applying stochastic multipath trip assignment to transit networks is described. The procedure extends an existing traffic assignment algorithm by (*a*) establishing strict criteria for transit zone definition; (*b*) using a comprehensive measure of disutility of transit trips; and (*c*) reconstructing the transit network so that all passenger movements are explicitly represented. The assignment procedure was tested on a large section of the Milwaukee County Transit System, which was specifically chosen to reveal any undesirable properties in the procedure. The assignment procedure was found to be free of those problems previously associated with applications of stochastic multipath traffic assignment in automobile networks.

Multipath trip assignment procedures have not yet been incorporated into the more widely used transit ridership forecasting models, such as the Urban Transportation Planning System (UTPS). Recent research on two lesser known models, EMME II (*1*) and the Transit Ridership Forecasting Model (TRFM) (*2*), has suggested that the validity of forecasts from UTPS-type models could be greatly improved with multipath trip assignment. The justification for still using a version of all-or-nothing assignment (*3*) in UTPS-type models is that existing multipath assignment procedures are extremely inefficient for large networks or will produce implausible assignments in some commonly encountered network structures.

The purpose of this paper is to demonstrate that a plausible and efficient multipath procedure can be built from existing theory. The basis of the procedure explored here is a stochastic, multipath trip assignment algorithm that originally was developed by Dial (*4*). Although it is considered to be efficient, Dial's algorithm has been correctly criticized for inaccurately representing travel behavior in many situations [see references (*5*) and (*6*) among others]. The research presented here shows that the undesirable properties of Dial's algorithm are of little consequence when transit networks are properly reconstructed as part of a larger multipath assignment procedure.

STRUCTURE OF TRANSIT NETWORKS

Much of the criticism of Dial's algorithm concerns its performance in automobile networks. However, some obvious facts about transit networks, which distinguish them from networks of other modes, are presented here. Transit networks consist of many relatively independent routes (or lines). The routes are not physically interconnected; passengers wishing to use more than one route must change buses (or trains). Access to transit networks is typically accomplished by walking. Different routes often share portions of their alignments, and a passenger has the choice of a route for a single leg of the trip. Most transit networks have a number of difficult route designs, such as one- and two-way loops, turnbacks, branches, and skip stopping.

There are also two less obvious facts that affect multipath trip assignment. First, passengers dislike transferring and will avoid as many transfers as possible (*7*). Second, passengers also dislike long walks at either end of their trips; thus, there is an industrywide standard for a service area of one-quarter mile to either side of a route. Alternative paths through the network that are too arduous, because of particularly long walks or excessive transfers, will never be considered. Riders will look for a better path, choose a different mode, choose a different destination, or entirely forego the trip.

With these facts in mind, an inspection of any transit map will lead a casual, but objective, observer to conclude that there are only a few passengers who have a reasonable choice of alternative paths. This conclusion markedly contrasts with path choice on automobile networks, where almost everyone has many path choices. Consequently, a transit, multipath trip assignment algorithm must first determine those passengers who may have an acceptable choice of paths. Although there are numerous exceptions, these passengers generally have both trip ends within the service areas of two different routes (*2*). Next, the algorithm must split these passengers among a small set of reasonable paths, based on their relative merits.

Because the primary criterion of whether a passenger actually has a choice is the location of trip ends, a multipath trip assignment algorithm must have an amicable set of zones. It has been argued (*2*) that improper zone definition is the major source of error in UTPS-type transit assignments. A fundamental characteristic of good zones is that their boundaries must coincide with service area boundaries. Thus, any given parcel of land can be immediately categorized by its proximity to the various routes. An example set of zones is shown in Figure 1. Zones of this nature are required for TRFM and are not technically difficult to create. There are a number of ways to produce such a set of zones, although shifting data from a set of traffic analysis zones (TAZs), or a set of census tracts, can be problematical. Recently, methods have been developed for redefining existing zones and will be discussed in forthcoming sections.

Zones based on service areas may be smaller than zones based on typical TAZ criteria. A normal consequence of smaller zones is an increase in the number of origin-destination (O-D) pairs and an increase in execution time. This increase in execution time is mitigated by the significant fraction of zones (hatched areas of Figure 1) that are not proximate to any route and, thus, can be ignored by the assignment algorithm.

There is conventional wisdom among researchers that path

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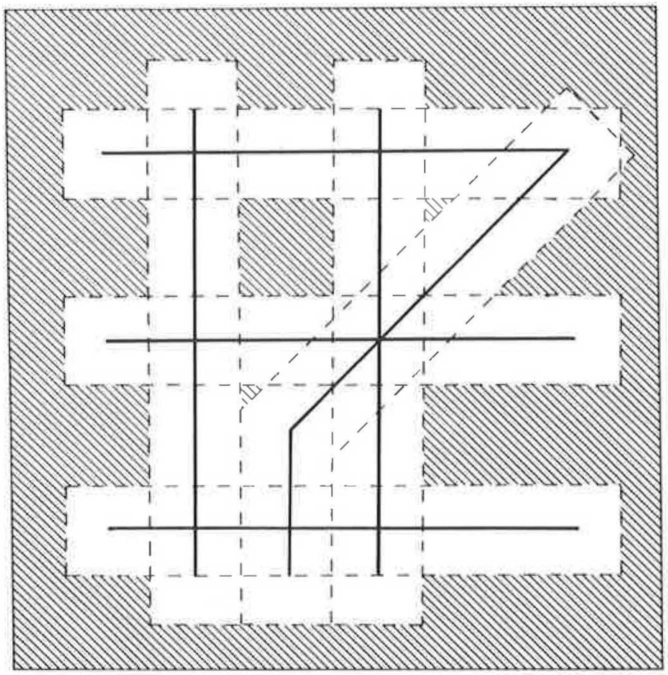


FIGURE 1 Hypothetical transit network and associated set of zones.

choice in transit networks is governed by travelers' perceptions of the relative merits of their available alternatives. Direct evidence in support of this notion is largely anecdotal; strong, indirect evidence is derived from other travel choice processes, such as mode split. Accordingly, this notion has been implemented into recent multipath trip assignment procedures (including EMME II and TRFM) with reported good results. Because there is no accepted method of finding all the necessary parameters in a fully configured path choice model, the various parameters must be adopted from another source—typically a mode split equation.

Another potential source of parameters for a path choice algorithm is psychological scaling (*8,9*). It has been shown that psychological scaling can produce a set of parameters consistent with those found from statistical estimation of mode split equations. In a psychological scaling experiment, subjects are asked to rate various trip descriptions. The ratings are independent of any choice process (mode choice or route choice). A particular advantage of psychological scaling is that subjects can be asked to evaluate infrequently encountered alternatives. Thus, it is possible to systematically build a much more complete model than is possible through other methods. For instance, TRFM uses essentially the same choice model for both mode split and trip assignment, and all but one of the default parameters are derived from a psychological scaling experiment.

The current research uses the disutility equation of the TRFM choice model because its source is well documented and it has undergone extensive testing as part of a complete modeling package. It should be pointed out that TRFM differs from UTPS-type models (the subject of this paper) principally because it is designed to forecast ridership on a single route. The conclusions of this study would probably remain unchanged if another, equally reliable, disutility equation were substituted.

The disutility of a transit trip may be represented in terms of weighted components of travel time and penalties for various actions (*9*). The units of disutility can conveniently be taken to be travel time, typically in minutes. Thus, when access to transit is by walking:

Disutility = (access walking time) (walking weight) + initial waiting penalty + (waiting time) (waiting time weight) + riding time + (transfer time) (transfer time weight) + (transfer penalty) (number of transfers) + (egress walk time) (walking weight) + (fare)/(value of time) (1)

The weights and penalties vary according to the environmental conditions for the particular trip component. For example, the transfer penalty has been noted to be considerably smaller for a timed transfer than for a normal, uncoordinated transfer (*7*). TRFM's default value of the transfer penalty under normal conditions is 23 min. This penalty is a conservative estimate; there is substantial evidence to suggest that the penalty should be larger—perhaps as high as 45 min. It should be noted that the full effect of a transfer in mode or route choice also includes the transfer time multiplied by the transfer time weight (defaulted at 1.6 for TRFM).

If path choice is to be made, strictly on the basis of disutility, then it is evident that the most important element of a transit trip is a transfer. It is, therefore, important that transfers be carefully represented in a multipath trip assignment procedure. This cannot be accomplished by simply using a more elaborate path choice model. Rather, it is necessary to perform a major reconstruction of the whole transit network. Network reconstruction will be discussed after a brief review of Dial's algorithm.

REVIEW OF DIAL'S ALGORITHM

Dial's algorithm is a clever modification of the standard Moore algorithm for finding the shortest path through networks. It requires some extra calculation and memory, but like the Moore algorithm, Dial's algorithm has a computation time that is roughly proportional to the number of links in the network. A plot of computation time against the size of network for path building and loading to a single trip destination from all trip origins is shown in Figure 2. For the record, these times were measured on an IBM-PC/AT, without a math coprocessor, running Turbo Pascal. A math coprocessor improves computation time by about 20 percent.

Dial's algorithm simulates the behavior of many people attempting to travel from a single origin to a single destination. An example trip is illustrated in Figure 3. (For those already familiar with Dial's algorithm: the sequence of events along this trip follows the backward pass.) As the travelers progress through the network, they encounter a number of intersections. Each intersection is a decision point. The algorithm assumes that the travelers have good, but not perfect, knowledge of what lies ahead. Any traveler will choose a direction (for example, a single link) on the basis of the shortest path disutility to the destination, given that direction. For example, at Intersection A

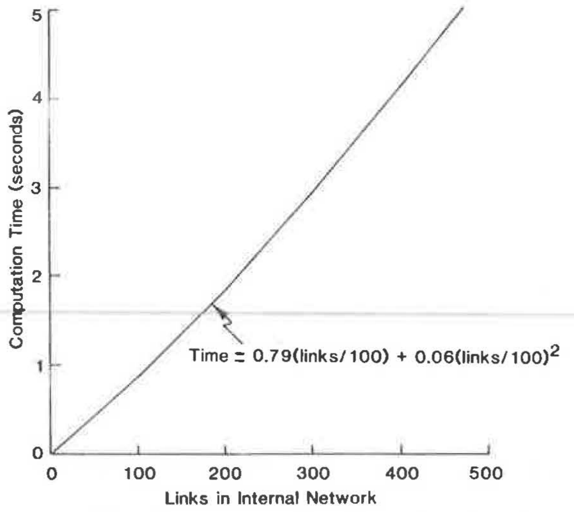


FIGURE 2 Computation time from all origins to a single destination.

it is found that there are two choices of direction. Link 1 has the lowest shortest path disutility to the origin (20 min versus 24 min), therefore this direction will draw most of the travelers. Some of the travelers progress to Intersection B. Here there are technically three choices of direction. However, Dial's algorithm eliminates Link 5 as a possible direction because travelers are taken farther away from their destination. Whatever paths are chosen, all travelers eventually reach their destination.

The behavioral underpinnings of Dial's algorithm may be succinctly stated: (*a*) travelers choose a direction (or link) at every intersection, (*b*) the only directions that will be considered are those that permit travelers to get closer to their destination, and (*c*) travelers are more likely to choose a direction that has a smaller shortest path disutility to the destination.

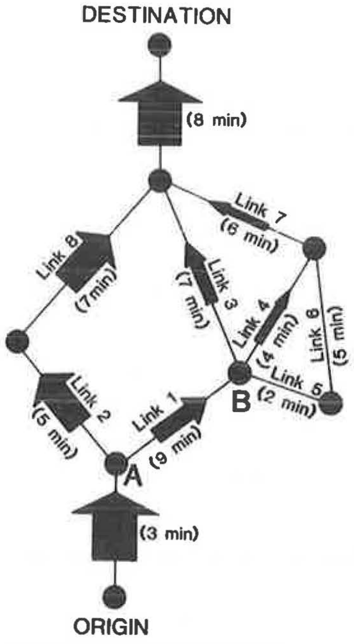


FIGURE 3 Example of path choice in Dial's algorithm.

Dial's specific functional form for handling choice of direction computes the probability (p_{ij}) that a rider, presently at node *i*, chooses to travel to node *j*. That is:

$$p_{ij} = W_{ij} / \sum_{\substack{\text{all}\\ \text{feasible}\\ j}} W_{ij} \qquad (2)$$

where

$$W_{ij} = \exp\,[\theta(d - d_j - d_{ij})] \qquad (3)$$

and where

θ = a calibrated parameter,
d_i = shortest path disutility from node *i* to the destination,
d_j = shortest path disutility from node *j* to the destination, and
d_{ij} = disutility on the link between node *i* and node *j*.

For feasible paths, d_i will always be larger than d_j, at most by the amount d_{ij}. It is important to note that the value of W_{ij} attains a maximum value of 1 for any direction that is on the shortest path to the destination.

Dial's algorithm considers only a subset of the paths between an origin and destination: those that always take travelers closer to their destination. As will be explained more fully, this subset is often quite small for transit networks. Typically, only one direction can be chosen at any intersection.

The most serious criticism of Dial's algorithm concerns a situation that occurs often in transit networks, for example, when there are more than two choices of direction. This situation is illustrated in Figure 4. Here a traveler is faced with a choice between one superior direction (Path 1) and four inferior directions that are just minor variations of the same path (Path 2). Dial's algorithm could assign many more travelers to all parts of Path 2 than to Path 1.

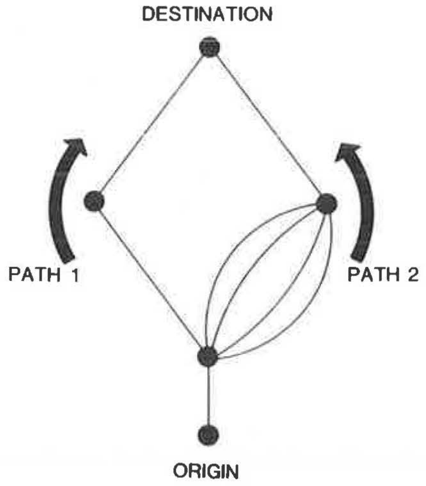


FIGURE 4 Illustration of an argument that Dial's algorithm is biased by the number of alternative directions.

A second look at this criticism is worthwhile. It can be argued that Dial's algorithm is indeed closely representative of normal travel behavior of transit riders. In transit networks, choices of direction are only possible at stops or at potential transfer points. Assume for this example that the differences in disutility between the two paths are due entirely to differences in in-vehicle time; headways for all directions are identical. The traveler, when making a choice of direction, is standing on the curb. Choice is largely related to chance. The traveler will most likely board the first bus that arrives at the transfer point. Because headways are equal, buses leading to Path 2 will arrive with four times the frequency of Path 1. Consequently, it is logical to expect Path 2 to be more heavily used. The aforementioned criticism of Dial's algorithm appears, at worst, to be a minor nuisance rather than a fatal flaw.

Users of UTPS are familiar with the concept of frequency split. When each of two (or more) bus routes entirely serves the same O-D pair, UTPS can be directed to split the trips between the routes according to their respective frequencies. It has been seen that Dial's algorithm, if properly implemented, will do exactly the same thing.

However, Dial's algorithm will not, in general, properly perform a frequency split if alternative paths involve more than a single route. Consider the situation, shown in Figure 5, of a choice between Path A and Path B, both of which involve a transfer. All headways and in-vehicle times are identical. It is clear that Dial's algorithm will produce a 50/50 split at node *U*, even though Path A should be preferred. The better set of transfer opportunities at transfer point *y* is not reflected in the choice between Route 5 and Route 1 at the origin.

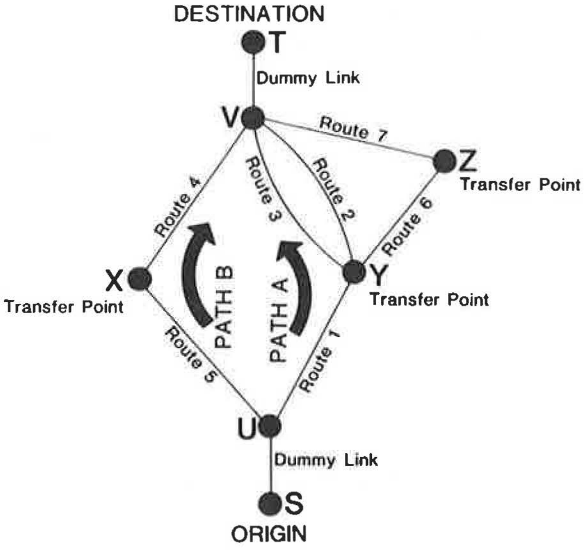


FIGURE 5 Hypothetical network showing lack of symmetry in Dial's algorithm.

TRANSIT NETWORK RECONSTRUCTION

It is rare that anyone considers the differences between the internal and external representations of a transit network. The external representation is the one that the network designer provides to the multipath assignment procedure, and the internal representation is the one that is actually used for path building and loading. For transit assignment, a strong case can be made for these two representations to be made distinct from each other.

The purpose of the external network is to permit the user to accurately transmit all relevant data to the mathematical model. The trend in recent years has been to show and edit the network graphically on a CRT display. Both TRFM and EMME II have this feature. Ideally, the external network should be free of extraneous detail; it should not contain artificial network elements (transfer links and centroid connectors); and it should be to scale. In other words, the external representation should look much like a system map that is provided to riders. Because there are only a few easily understood rules for drawing an external network, there is a strong likelihood that the network will be free of serious structural deficiencies.

The test network used for this research is shown in Figure 6. It is part of the Milwaukee County Transit System (MCTS). The network was drawn, and numerical data was entered through the General Network Editor (GNE) developed at the University of Wisconsin-Milwaukee. GNE is a graphics editor and network data-base manager that is dynamically configurable to nearly any type of transportation application.

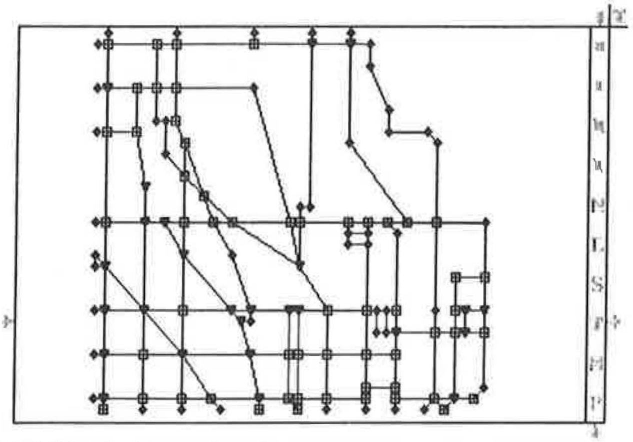
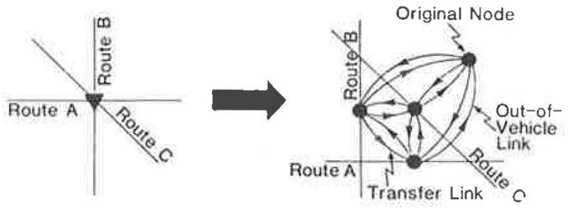


FIGURE 6 Test network—northeast portion of MCTS.

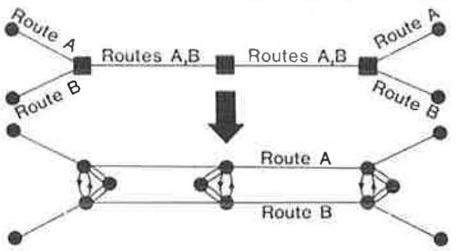
The purpose of the internal network, on the other hand, is to permit an accurate simulation of the behavior of travelers. It would include all the necessary artificial network elements, and thus would be substantially more complex than the external network. The way in which the external network is reconstructed into an internal network is based on assumptions about path choice decision processes. Consequently, the process of creating the internal network is part of the assignment model and not just an innocuous manipulation of data.

A highly formal reconstruction procedure has the additional advantage of standardization. Dial's algorithm is known to be sensitive to the way in which the actual system is represented as a network (*10*). With a formal reconstruction procedure, the algorithm is likely to yield the same result, regardless of who draws the external network.

Of particular concern to the current research is the reconstruction of transfer points. A reconstruction scheme is shown in Figure 7. The three-way transfer point is replaced by a subnetwork of four nodes and six two-way links. The original node is isolated from the rest of the network by three links that represent out-of-vehicle time. Three additional links represent the six possible transfers between the three routes. In general, an N-way transfer point requires $(N + 1)$ nodes and $[N + N(N - 1)/2]$ two-way links. It is interesting to note that when UTPS was first written for the IBM 7090 computer (*3*), transfer point reconstruction was considered but was rejected as being too computationally inefficient.



Three-way Transfer Point



Multiple-Route Links

FIGURE 7 A network reconstruction scheme.

Also shown in Figure 7 is a reconstruction of links that each represent more than a single route. Such links occur when two or more routes share the same alignment; but there are other times when multiple-route links are useful. For example, routes with two branches are most accurately shown as two distinct routes. The joined portion of the route must then be described by a series of multiple-route links and transfer points. The transfer points ensure that riders cannot travel between the two branches without transferring.

As might be expected, the internal network can be considerably larger than its external counterpart. The transit network of Figure 2 has 130 nodes and 187 links. The internal network is almost three times as large, with 325 nodes and 574 links.

A straight application of Dial's algorithm on a reconstructed network can produce a small but annoying amount of frivolous transferring. That is, a few travelers will appear to make two or more transfers at a single transfer point. Frivolous transferring is easily eliminated by amending Equation 3 so that

$$W_{ij} = 0, \text{ if } -d_i + d_j + d_{ij} > a_k \qquad (4)$$

The value of a_k is set to be slightly less than the disutility on any transfer link at a given transfer point k. This constraint has an additional effect of eliminating otherwise feasible paths that are extremely poor choices.

TESTS OF THE ASSIGNMENT PROCEDURE

The purpose of the following tests is to determine if the assignment procedure performs as expected: that it is conservative in its generation of paths; that it is unbiased with respect to the number of alternative directions at different points in the network; that it is symmetrical where it should be; and that it consistently applies a unified model of travel behavior. In other words, the tests should determine if the full procedure has properly dealt with the criticisms of Dial's algorithm.

The test network contains approximately one-fifth of the MCTS. This particular system was selected because it is essentially a grid with a few radial routes. A grid system provides a maximum of transfer possibilities and therefore offers the most demanding case for a multipath assignment procedure. This particular section of MCTS contains routes with branches, routes with one-way loops, other one-way sections, and multiple routes sharing the same alignment. The section also contains 26 multiple-transfer points, one of which is the intersection of five different routes. The test network has a service area with a population of about 200,000. All headways and running times are for the midday period. None of the transfers are coordinated.

Using GNE, data input procedures were designed to ensure that the full detail of the actual transit system was preserved. All possible path alternatives (rational or irrational) that were available to actual riders were available to the assignment procedure. The value of θ (0.06) was established during an earlier study by running TRFM on two subnetworks of MCTS (*2*).

The tests consisted of 30 runs of the procedure, each assigning 100 riders from a single origin to a single destination. By inspecting the loadings on the links, it was possible to determine the feasible paths and the split of riders at each transfer point. The trips (O-D pairs) were not chosen at random. Instead, they were chosen in an attempt to force the procedure into producing odd results. The selected trips required an unrepresentatively large number of transfers. Twelve of the trips could be made without transferring; fifteen of the trips could be made with a minimum of one transfer; and three trips needed a minimum of two transfers. The trips were also unrepresentative in the number (15 out of 30) that had both their origin and their destination at transfer points. Most of the trips were selected either to follow a string of multiple-route links or to start, end, pass near, or pass through one of the more complex multiple-transfer points.

It is difficult to obtain a clear idea of the performance of the algorithm without inspecting the CRT display of each result. The example trips shown in Figure 8 and the summary statistics given in Table 1 support the general conclusions that are made here.

All paths of two separate trips are shown in Figure 8. Trip A (going between Origin A and Destination A′) has one of the more complex set of paths among the 30 trips. Origin A is just a regular stop, while Destination A′ is a five-way transfer point. This trip requires a minimum of two transfers and, thus, would

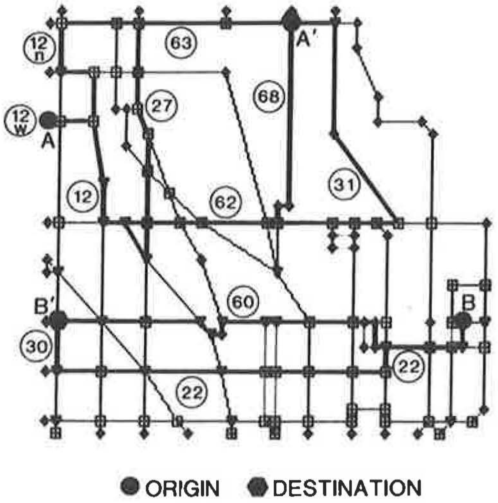


FIGURE 8 Two examples of path generation.

be quite unusual. Even though there are many possible paths, the maximum number of feasible alternative directions faced by any rider is only two. There are four distinct paths involving seven different routes. None of the paths had more than two transfers.

The second trip (B to B′) in Figure 8 is much more typical of the 30 test runs. This trip requires a minimum of one transfer. Origin B is a four-way transfer point. Only two paths, both quite reasonable, were generated. Any other path would have required more than the minimum of one transfer or would have required considerably more in-vehicle time. The difference in ridership (70 percent to Route 22 and 30 percent to Route 60) between the two paths is due entirely to the relatively small transfer time from Route 22 to Route 30.

Statistics on path generation for all 30 trips are summarized on Table 1. Note that there is a strong relationship between the number of paths generated and the minimum number of transfers required. Trips that required no transfers, with just two exceptions, had only one feasible path. More than one-half (8 of 15) of single-transfer trips had only one feasible path, although there were trips with as many as six paths. Trips that required at least two transfers averaged less than three paths. Because of large disutility differences between automobile and transit modes, multiple-path trips are less likely to be chosen by potential transit riders.

TABLE 1 SUMMARY OF PATH GENERATION FOR 30 TEST RUNS

Minimum No. of Transfers	No. of Test Runs	Mean Paths Generated	Mean Transit Disutility	Mean Automobile Disutility
0	12	1.17	44.8	10.8
1	15	1.87	87.2	14.6
2	3	2.67	137.7	14.2

DISCUSSION OF THE PROCEDURE

The assignment procedure requires more computation time than a UTPS-type, all-or-nothing assignment algorithm. The increase in computation time depends on the number of multiple-transfer points and the sizes of the original zones. Based on the MCTS network, increases in computation time of between 200 to 400 percent should be anticipated.

It is important to recognize that the described assignment procedure cannot be readily applied to most existing transit networks or to most existing sets of traffic analysis zones. Incompatibility of networks is not particularly serious, given the new generation of network editors (such as GNE). For example, the UTPS network for MCTS could be completely redrawn in approximately 1 person-week. Incompatibility with existing sets of zones is less easily solved because (*a*) the zones required for the assignment may differ from those required for other model steps, and (*b*) all travel data has already been aggregated to the original zones. Reaggregation of data can be prohibitively expensive.

Areal interpolation is a promising method of developing a new set of zones from an old set (*11,12*). Inputs to an areal interpolation program include boundaries of both source and target zones and a statistic (number of households) on each source zone. The program then estimates the statistic for each target zone. For example, Tobler's Pycnophylactic Histospline Interpolation Model has been successfully used at the Center for Urban Transportation Studies for a comparable problem—moving demographic data from census tracts to TRFM zones (*13*). With areal interpolation it is possible to retain the original TAZs for other parts of the travel demand forecast, while adopting entirely new zones for transit assignment. In this case, it is only necessary to interpolate the transit trip table.

The multipath assignment procedure should not affect current iterative methods of handling user equilibrium in transit networks (*14*). Larger-than-planned link volumes manifest themselves by (*a*) increasing boarding and alighting times, (*b*) increasing the amount of standing and thereby increasing negative perceptions about riding time, and (*c*) prompting the transit operator to add buses or trains. The combined effects can be quite complex; in many cases an increase in ridership reduces disutility as additional buses are supplied. Much more research is required before a practical and completely integrated equilibrium or multipath trip assignment procedure can be assembled.

CONCLUSIONS

The assignment procedure described in this paper retains the speed and memory efficiency of Dial's algorithm (*3*). However, the procedure requires a specially configured system of zones based on service area boundaries, and a network on which every possible transfer and waiting period are explicitly represented by links. These artificial links are not seen by the network designer but are created during a network reconstruction step in the procedure.

The extensions produced an assignment procedure that behaved in a manner consistent with current understanding of how transit riders choose paths. Tests of the procedure, under unusually harsh network conditions, failed to reveal any of the undesirable traits that had been attributed to Dial's algorithm. For the most commonly made trips, the procedure was properly conservative in path generation. The procedure revealed only one best path between an origin and destination, unless there were close alternatives. When alternative paths were generated, the split of riders among the paths closely followed the widely accepted principle of frequency split. Because of the dominating effect of out-of-vehicle time on path disutility, Dial's algorithm works well on transit networks, even though it had been dismissed as unusable by other researchers.

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