surement of performance.

The second major development is the concept of budgeted delay. This variable accounts for the amount of time a traveler budgets for a trip. It is a function of the mean travel time for a trip and the variability of travel time for a trip and corresponds to an upper percentile point on the travel time distribution. Reductions in budgeted time are a more accurate measure of the benefit of a bus-priority scheme than reductions in mean time. Use of budgeted time in a case-study evaluation produced no significant difference to the results, although this is not likely to be a general finding.

Finally, and most importantly, many bus-priority schemes that have been evaluated on the basis of net reductions in mean travel time may have been incorrectly labeled as infeasible. Reevaluation of these schemes on the basis of perceived, budgeted time changes would probably result in many of them being relabeled as feasible TSM schemes that can contribute to the more efficient operation of the existing transportation infrastructure.

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Impact of Short-Term Service Changes on Urban Bus Transit Performance

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This paper examines the impact on a fixed route of small changes in three operational policy variables: frequency, number of bus stops, and fare. Analytical expressions are developed that trace the impact of each variable on various other system variables, which leads to an assessment of changes in selected measures of efficiency and effectiveness. The application of the methodology is demonstrated by a case study of a selected bus route in a medium-sized Indiana city. Three specific options are evaluated in terms of alternative frequency, number of stops, and fare policies. Since none of the options was actually implemented, the paper reports only on a theoretical analysis of the changes that might be expected under each option. The results indicate that significant improvements are possible in most of the efficiency and effectiveness measures under all three options examined. The technique does not require an extensive amount of data or calibration effort; instead it relies on information generally available from the records of a transit company and reasonable assumptions where necessary.

Much effort is currently being directed toward gaining a better understanding of urban transit performance. Under public ownership, transit systems are being subsidized heavily by federal, state, and local funds. These subsidies are necessary if transit companies are to continue to provide service to the public even when they cannot recover their operating costs from the farebox. Under these circumstances, if service improvements are evaluated solely on the basis of cost recovery, few projects, if any, would be implemented. Previous studies of short-term changes in service have concentrated on ridership, costs, and revenue impacts; little emphasis was given to their impact on accepted measures of performance.

This paper presents a methodology for relating short-term service changes to changes in selected measures of performance. Particular reference is made to bus transportation in medium-sized urban areas. Specifically, an examination is made of the effect of changes in three major operational policy variables along a fixed bus route. These variables are (a) frequency of service, (b) spacing between stops, and (c) basic fare.

The emphasis is on the development of a systematic approach that traces the impact of each policy variable on various other system variables, which will lead to an assessment of the appropriate performance measures. The most important aspect is to establish reasonable impact relationships between the policy and the impact variables as well as relationships among the impact variables themselves.

A number of factors were considered of prime importance and common to the development of the specific relationships and the overall methodology. First, transit management and transportation planners should find the procedure simple and quick to apply to provide a reasonable assessment of the impacts. Second, the relationships developed should maintain a sound theoretical base, but they should not be unduly complex or require a great deal of modeling and calibration effort. Third, the procedure should not be too restrictive in the sense of being applicable only to unique situations. In other words, the methodology should be general and adapt readily to different environments. Last, use of the procedure should not be very costly in terms of data requirements. Most of the data required should be available from the usual records kept by the transit operators.

Figure 1. Linkages and ridership.

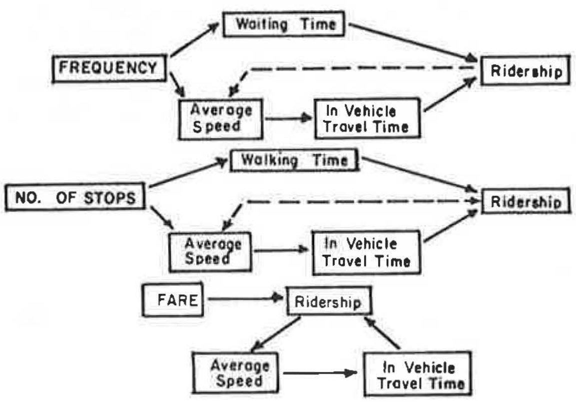


Figure 2. Linkages and system costs and revenues.

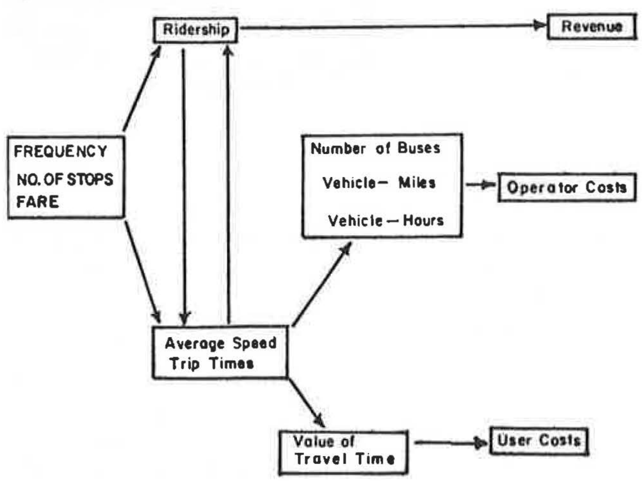
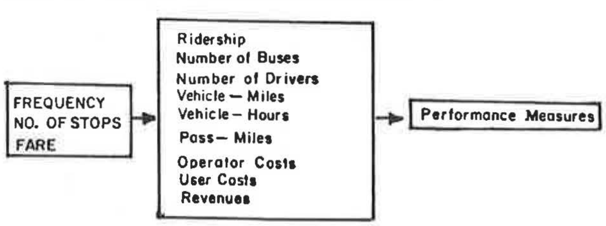


Figure 3. Linkages and performance measures.



IDENTIFICATION OF IMPACTS

On any given bus route, the entire spectrum of variables that can be affected directly or indirectly by changes in the operational policy variables may be grouped as follows:

1. Service variables—Average operating speed, vehicle travel time, walking time, and waiting time;
2. Output variables—Ridership, passenger miles, vehicle miles, vehicle hours, and revenue;
3. Resource variables—Number of buses, number of drivers, operator costs, and user costs; and
4. Performance measures—Cost efficiency (operator and total cost per vehicle hour, operator and total cost per vehicle mile, operator and total cost per passenger, and operator and total cost per passenger mile), revenue efficiency (revenue per dollar of operating cost and revenue per vehicle mile), driver utilization efficiency (vehicle miles per driver pay hour and passengers per driver pay hour), vehicle utilization efficiency (annual vehicle miles per vehicle and annual passengers per vehicle), user cost effectiveness (user cost per passenger and user cost per dollar of operating cost), ridership effectiveness (passengers per vehicle mile, passengers per vehicle hour, passengers per dollar of operating cost, and passenger miles per seat mile), and other measures (e.g., deficit per passenger).

The operator costs are the direct cost of bus operation computed as a function of the total vehicle hours and vehicle miles operated. Hourly costs include driver wages, fringe benefits, and advertising. Distance costs include depreciation, maintenance, parts, fuel, oil, tires, insurance, tickets and timetables, and right-of-way costs. The user costs consist of the value travelers place on their walking, waiting, and vehicle travel times.

The measures of performance selected here are those that are influenced most by changes in the policy variables and are felt to cover adequately major areas of interest. A more complete treatment of performance measures can be obtained by reference to other studies (1-4).

ASSESSMENT OF IMPACTS

The various linkages among the relevant variables are shown schematically in Figures 1, 2, and 3. The most important outcome is the change in ridership due to changes in the operational policy variables. This change occurs as a result of the inherent elastic nature of demand in response to changes in the level of service characteristics.

Figure 1 shows, for example, that an increase in frequency will decrease waiting time, increase the average speed, and decrease vehicle travel time, which will result in an increase in ridership. An increase in the number of stops decreases walking time but also decreases the operating speed, which will cause an increase in the vehicle travel time. The effect on ridership then depends on the relative elasticities and magnitudes of the change of waiting time and vehicle travel time.

In the case of a fare change, an increase in fare, for example, will decrease ridership as a direct result of the negative elasticity of demand with respect to fare. However, this decrease in ridership might improve the average operating speed and cause a decrease in the vehicle travel time, thereby inducing an increase in ridership. The net change in ridership may still be negative, depending, however, on the relative magnitudes of these opposing changes. This reverse effect of the change in ridership on the average bus speed is also present in the case of changes in frequency and number of stops, as shown by the dotted lines in Figure 1.

Figure 2 shows the linkages of the total system costs and revenues. Total costs are the sum of operator costs and user costs. The change in operator costs is related directly to the change in vehicle hours and vehicle miles of bus operation; however, change in user costs is a function of the change in the travel time components.

Eventually, interest lies in the effect these changes have on the performance of the system. This is measured through changes in the appropriate performance indicators obtained via changes in variables such as ridership, costs, revenues, vehicle miles, and vehicle hours, as shown in Figure 3.

Analytical expressions to represent the various linkages were developed as follows.

Average Operating Speed

The variables that are characteristic along a given bus route are defined below (SI units are not given for the variables of this model because its operation requires that they be in U.S. customary units.):

- L = round trip route length in miles;
- Y = number of stops per mile;
- Q = average hourly demand (i.e., the number of passengers served along the entire route per hour);
- M = average trip length per passenger in miles;
- X = frequency of service in buses per hour;
- S^* = running speed of bus in miles per hour;
- S = average operating speed over the entire route in miles per hour;
- ϵ = time spent per passenger in boarding or alighting from a bus, converted to hours; and
- δ = time spent in a stopping and starting maneuver, converted to hours.

In addition, the following assumptions are made:

1. Origins and destinations are uniformly distributed along the route,
2. The probability distribution of the number of passengers that board a bus at a given stop follows a Poisson distribution, and
3. Passengers are equally likely to get off at any stop, and they make their decisions to do so independently of one another.

Mohring (5) showed that under these assumptions the total round-trip time may be obtained as

$$L/S = (L/S^*) + (2Q\epsilon/X) + \delta YL\,(1-e^{-2Q/XYL}) \quad (1)$$

where

- L/S = the round-trip time,
- L/S^* = the running time (i.e., the time spent when the bus is in motion),
- $2Q\epsilon/X$ = the time spent in loading and unloading passengers,
- δYL = the time spent in starting and stopping maneuvers, and
- $(1-e^{-2Q/XYL})$ = the probability that a given stop is made.

Dividing Equation 1 by L,

$$1/S = (1/S^*) + (2Q\epsilon/XL) + \delta Y\,(1-e^{-2Q/XYL}) \quad (2)$$

which gives the desired expression for the average operating speed as a function of demand, frequency, number of stops, and the running speed of the bus.

In-Vehicle Travel Time (IVTT)

This is simply the average trip length divided by the average speed.

$$IVTT = 60M/S, \text{ in minutes} \quad (3)$$

Walking Time (WKT)

In the absence of specific knowledge about the distribution of actual walking distances, we assume that the maximum walking distance will be one-half of the distance between stops; therefore, 1/4Y miles can be taken as the average walking distance. Since walking occurs at both ends of the trip, the total walking distance per trip is 1/2Y.

If w is the walking speed in miles per hour,

$$WKT = 30/wY, \text{ in minutes} \quad (4)$$

Waiting Time (WTT)

For average waiting delays, the following relationships were used:

$$WTT = 30/X, \text{ for } X \geq 2, \text{ in minutes} \quad (5a)$$

$$WTT = 8 + 14/X, \text{ for } X < 2, \text{ in minutes} \quad (5b)$$

The assumption is that the average waiting time will be equal to one-half the headway for headways less than 30 min and vary linearly between 15 and 22 min for headways between 30 and 60 min. Headways greater than 1 h are not expected.

Ridership

If we assume that the demand function is of the product form with constant elasticities, the new ridership level (Q_1) after a small change (Δ) in the service variables can be obtained from

$$Q_1 = Q_0\{1 + \alpha[\Delta(IVTT)/IVTT_0] + \beta[\Delta(WKT + WTT)/(WKT_0 + WTT_0)] + \gamma[\Delta(FARE)/(FARE_0)]\} \quad (6)$$

where α, β, and γ are the demand elasticities with respect to vehicle travel time, excess travel time, and fare, respectively. Subscript zero refers to the level before the change in service variables.

Any change in the operational policy variables (namely, X, Y, and FARE) is analyzed by sequential solution of Equations 2-6. For greater accuracy, however, the change in X, Y, or FARE is divided into N smaller increments (positive or negative) and the equations are solved N times.

The remaining impact variables are obtained as follows: Let there be n distinct periods during which any of the variables such as ridership, fare, and frequency may be different, and let i denote the i^{th} such period where i = 1, 2, . . . n. The hourly impact variables in the

i^{th} period are then obtained as below:

Revenue

$$(\text{revenue per hour})_i = (\text{ridership per hour})_i \times (\text{FARE})_i \quad (7a)$$

or

$$REV/h_i = Q_i \cdot FARE_i \quad (7b)$$

Vehicle Miles

$$(\text{vehicle miles per hour})_i = (\text{frequency})_i \times (\text{round trip length}) \quad (8a)$$

or

$$VMPH_i = X_i \cdot L \quad (8b)$$

Vehicle Hours

$$(\text{vehicle hours per hour})_i = (\text{frequency})_i \times (\text{round trip time})_i + \text{layover} \quad (9a)$$

or

$$Vh/h_i = X_i \cdot (L/S_i)\,(1 + LOF) \quad (9b)$$

where, LOF = the layover time factor as a fraction of round trip time.

Passenger Miles

$$(\text{passenger miles per hour}) = (\text{ridership per hour})_i \times (\text{average trip length})_i \quad (10a)$$

or

$$PM/h_i = Q_i \cdot M_i \quad (10b)$$

To obtain the values on an annual basis, the hourly values are multiplied by the number of annual hours of the respective period and summed over all the n periods.

Number of Buses

The number of buses required during any period i is computed as follows:

$$(\text{number of buses})_i = (\text{frequency})_i \times (\text{round trip time})_i \quad (11a)$$

or

$$NBUS_i = X_i \cdot (L/S_i), \text{ rounded up to nearest whole number} \quad (11b)$$

Number of Drivers

The number of drivers required on any one day is largely a function of run cutting, labor rules, and the peak to off-peak service ratios. However, a reasonable estimate may be obtained by making certain simplifying assumptions. Assume, for example, a certain average ratio of the number of pay hours to platform hours relevant to a particular situation. Let this ratio be denoted as R. Assume also that a driver is paid for an average of N hours per day. Then, an estimate of the number of drivers required on any day can be obtained from

$$\text{Number of drivers} = (\text{vehicle hours per day} \times R)/N \quad (12a)$$

or

$$NDRVR = (Vh/D \cdot R)/N \quad (12b)$$

where Vh/D = total number of vehicle hours per day.

Operation Costs

The operating cost in the period i is obtained from

$$(\text{operating cost per hour})_i = a\,(\text{vehicle hours per hour})_i + b\,(\text{vehicle miles per hour})_i \quad (13a)$$

or

$$OC/h_i = a\,Vh/h_i + b\,VMPH_i \quad (13b)$$

where a and b are the unit costs of bus operation per vehicle hour and vehicle mile, respectively, for a bus of a particular size.

User Costs

This cost is taken as a function of the dollar value that users place on their travel time, obtained from

$$(UC/P)_i = V(IVTT)_i + \eta V(WKT + WTT)_i \quad (14)$$

where

$(UC/P)_i$ = the user cost per passenger in the period i,
V = dollar value of vehicle travel time, and
ηV = dollar value of excess time (η ranges generally from two to three).

Hence, the user cost per hour (UC/h) in the period i is obtained as

$$(UC/h)_i = (UC/P)_i \cdot Q \quad (15)$$

APPLICATION OF THE METHODOLOGY

The application of the methodology to a case study is illustrated here by an examination of a typical route selected from a transit system in a midwestern city that has a population of 600 000. First, a comparison is made of the results obtained by using the relationships developed above with those obtained from records of the transit operator. Then, an analysis is presented of specific policy alternatives in terms of their impact on performance.

Route Data and System Information

Most of the information required for the study was available from the transit corporation. The specific information is given below:

Route selected—English Avenue, route number 10;
Round trip length (L)—19.1 miles;
Number of stops (Y)—9.11/mile;
Number of periods (N)—4 (weekday peak and off-peak, Saturday peak and off-peak); and
Hours of service (weekdays and Saturdays)—peak, 7:00-9:00 a.m. and 3:30-6:00 p.m.; off-peak, 6:00-7:00 a.m., 9:00 a.m. -3:30 p.m., and 6:00-7:00 p.m.;
Running speed (S*)—27.5 mph;
Average trip length (M)—0.56 mile;
Fare—\$0.50, all periods;
Average loading and unloading time (ϵ) (computed from small-scale, on-board survey)—4.66 s/passenger;
Average stopping and starting time (δ) (computed from small-scale, on-board survey)—19.29 s/stop;
Assumed walking speed = 3 mph;
Assumed value of vehicle travel time (V)—\$2.00/h;

Table 1. Summary of annual statistics for the base case generated by the model.

Variable	Weekday Peak	Weekday Off-Peak	Saturday Peak	Saturday Off-Peak	Peak Plus Off-Peak Weekday	Peak Plus Off-Peak Saturday	Annual Total
Headway (min)	20	45	45	45			
Number of buses	4	2	2	2	4	2	4
Layover factor	0.247	0.291	0.424	0.553			
Number of drivers per day					5	4	
Annual ridership	88 484	100 724	4 837	9 618	189 208	14 455	203 663
Annual passenger miles	49 551	56 405	2 709	5 386	105 956	8 095	114 051
Annual vehicle miles	65 752	55 198	6 704	11 256	120 950	17 960	138 910
Annual vehicle hours	4 590	4 335	468	884	8 925	1 352	10 277
Annual revenues ($)	44 242	50 362	2 418	4 809	94 604	7 227	101 831
Annual operator costs ($)	85 430	76 787	8 711	15 659	162 217	24 370	186 587
Annual user costs ($)	71 011	138 462	6 209	13 111	209 473	19 320	228 793
Annual total costs ($)	156 441	215 249	14 919	28 769	371 690	43 688	415 378
Annual deficit ($)	41 188	26 425	6 293	10 850	67 613	17 143	84 756

Note: Figures may not add exactly due to rounding errors.

Assumed value of waiting and walking time (ηV)—$4.00/h;

Bus size—47 seats;

Unit cost of bus operation—a = $10.5243/vehicle-h; b = $0.5646/vehicle mile;

Average ratio of pay hours to platform hours (R)—1.20;

Average pay hours per driver—9.25/day; and

Assumed demand elasticities—given below (6-8).

Variable	Weekday Peak	Saturday and Weekday Off-Peak
Vehicle travel time	-0.35	-0.45
Excess time (waiting and walking)	-0.70	-0.90
Fare	-0.20	-0.40

The layover factor (LOF) is computed from $1 + LOF = NBUS/(X \cdot L/S)$.

Headways, ridership, and hours of operation are as follows:

Measure	Time	Weekday	Saturday
Headways (60/x) (min)	Peak	20	40
	Off-Peak	45	45
Ridership (Q) (passengers/h)	Peak	77.11	20.67
	Off-peak	46.47	21.76
Annual hours of operation (based on 255 weekdays and 52 Saturdays/year)	Peak	1147.5	234
	Off-peak	2167.5	442

Comparison of Route Performance with System Average

First the model was used to obtain the annual output and resource variables in each of the four periods considered. The results are summarized in Table 1. The only route-specific data obtainable from the system records for comparison with those shown in Table 1 were annual weekday and Saturday vehicle miles and vehicle hours of operation. These values were found to differ by less than 10 percent, as given below.

Period	Annual Vehicle Miles	Annual Vehicle Hours
Weekday		
Actual	125 460	9873
Model	120 950	8925
Difference (%)	-3.6	-9.6
Saturday		
Actual	18 460	1381
Model	17 960	1352
Difference (%)	-2.8	-2.1

We were able to obtain data on most systemwide performance measures. A comparison of these with the route-specific values (obtained by using the model) is given in Table 2. The annual performance values obtained with the model are in close agreement with the system averages. The difference is less than 15 percent for all except the passengers per vehicle mile measure, which is about 33 percent below the system average. Comparison of weekday ridership counts on routes that have comparable service levels showed route 10 to have a much lower patronage per mile, which probably accounts for the lower route-specific passengers per vehicle mile value.

An important result to note in Table 1 is the relatively high layover factor in each period. Since this factor reflects the idle time between successive runs as a fraction of the total round trip, it seems that, if buses adhere strictly to headways as scheduled, they spend a large fraction of the time laying over between runs—25-30 percent on weekdays and 42-55 percent on Saturdays. Depending on individual labor contracts and scheduling constraints, layover times should not be greater than 5-10 percent of the round-trip time for greater performance efficiency.

Analysis of Specific Options

In order to demonstrate the possible use of the methodology by transit operators, a set of specific service improvement options was evaluated. These alternatives were formulated as shown below, along with the existing base case.

Alternative	Headways (min) Weekday Peak	Weekday Off-Peak	Saturday Peak	Saturday Off-Peak	Number of Stops	Fare (cents)
Base case	20	45	40	45	9.11	50
Option 1	17	36	30	30	9.11	50
Option 2	24	36	30	30	9.11	50
Option 3	24	36	30	30	12.00	50, peak; 40, off-peak and Saturday

Option 1 represents an improvement in the headways for all periods; the number of stops and fare are unchanged. Option 2 is the same as option 1, but headway is increased to 24 min in the weekday peak period. Option 3 is the same as Option 2, but the number of stops is increased to 12.0/mile and fare is reduced to 40 cents during the weekday off-peak period and all day Saturday.

The results obtained for each option are summarized in Table 3. Option 1 results in a considerable increase in annual ridership and vehicle miles operated, as well as corresponding increases in revenues and operating costs. Although the operating deficit increases by $6328, the deficit per passenger decreases from $0.416 to $0.398. Except for small increases in the operating cost and total cost per vehicle hour, the remaining cost-efficiency indicators are generally improved and the driver and vehicle utilizations are increased significantly. The option is also effective in reducing the user cost per passenger and user cost per dollar of operating cost.

The service cutback in the weekday peak period in option 2 causes ridership to decline relative to option 1, but it is still higher than the base-case ridership. The

Table 2. Comparison of route performance with system average.

Performance Indicator	Route Specific Data Weekday	Saturday	Annual	System Average[a]
Efficiency				
Operating cost per vehicle hour ($)	18.18	18.03	18.16	20.51
Operating cost per vehicle mile ($)	1.34	1.36	1.34	1.60
Operating cost per passenger ($)	0.36	1.69	0.92	0.90
Operating cost per passenger mile ($)	1.53	3.01	1.64	1.62
Total cost per vehicle hour ($)	41.65	32.31	40.42	NA
Total cost per vehicle mile ($)	3.07	2.43	2.99	NA
Total cost per passenger ($)	1.96	3.02	2.04	NA
Total cost per passenger mile ($)	3.51	5.40	3.64	NA
Revenue per dollar operating cost ($)	0.58	0.30	0.55	0.55
Revenue per vehicle mile ($)	0.78	0.40	0.73	0.88
Vehicle miles per driver pay hour	10.26	9.34	10.13	NA
Passengers per driver pay hour	16.04	7.51	14.85	NA
Annual vehicle miles per vehicle	30 238	8980	34 728	36 771
Annual passengers per vehicle	47 302	7228	50 916	50 288
Effectiveness				
User cost per passenger ($)	1.11	1.34	1.12	NA
User cost per dollar operating cost ($)	1.29	0.79	1.23	NA
Passengers per vehicle mile	1.56	0.81	1.47	2.19
Passengers per vehicle hour	21.20	10.69	19.82	23.17
Passengers per dollar operating cost	1.17	0.59	1.09	1.11
Passenger miles per seat mile	0.019	0.010	0.017	0.021
Other				
Deficit per passenger ($)	0.36	1.19	0.42	0.41

[a]Numbers were obtained from a published report of the transit system.

Table 3. Comparison of alternatives.

Impact Variables	Base Case	Option 1	Option 2	Option 3
Output				
Annual ridership	203 663	228 568	208 147	221 025
Annual passenger miles	114 051	127 998	116 562	123 774
Annual vehicle miles	138 910	172 176	149 612	149 612
Annual vehicle hours	10 277	10 277	9 129	9 129
Annual revenues ($)	101 831	114 284	104 073	96 308
Resource				
Number of buses—weekday	4	4	3	3
Number of buses—Saturday	2	2	2	2
Number of drivers—weekday	5	5	4	4
Number of drivers—Saturday	4	4	4	4
Annual operator costs ($)	186 587	205 368	180 552	180 552
Annual user costs ($)	228 793	227 608	231 668	243 535
Annual total costs ($)	415 378	432 977	412 221	424 088
Efficiency				
Operating cost per vehicle hour ($)	18.156	19.983	19.778	19.778
Operating cost per vehicle mile ($)	1.343	1.193	1.207	1.207
Operating cost per passenger ($)	0.916	0.898	0.867	0.817
Operating cost per passenger mile ($)	1.636	1.604	1.549	1.459
Total cost per vehicle hour ($)	40.418	42.131	45.155	46.455
Total cost per vehicle mile ($)	2.990	2.515	2.755	2.835
Total cost per passenger ($)	2.040	1.894	1.980	1.919
Total cost per passenger mile ($)	3.642	3.383	3.536	3.426
Revenue per dollar operating cost ($)	0.546	0.556	0.576	0.533
Revenue per vehicle mile ($)	0.733	0.664	0.696	0.644
Vehicle miles per driver pay hour	10.126	12.551	13.171	13.171
Passengers per driver pay hour	14.847	16.632	18.324	19.458
Annual vehicle miles per vehicle	34 728	43 044	49 871	49 871
Annual passengers per vehicle	50 916	57 142	69 382	73 675
Effectiveness				
User cost per passenger ($)	1.123	0.996	1.113	1.102
User cost per dollar operating cost ($)	1.226	1.108	1.283	1.349
Passengers per vehicle mile	1.466	1.328	1.391	1.786
Passengers per vehicle hour	19.817	22.241	22.801	24.211
Passengers per dollar operating cost	1.092	1.113	1.153	1.224
Passenger miles per seat mile	0.017	0.016	0.017	0.018
Other				
Annual deficit ($)	84 756	91 084	76 479	84 244
Deficit per passenger ($)	0.416	0.398	0.367	0.381

most significant impact is a reduction of one in the number of buses and drivers required during weekdays. As a result annual operating costs are less, and the deficit is reduced to $76 479 compared to the base-case value of $84 756. There is also further improvement in the driver and vehicle utilization indicators and in the operating cost efficiencies, except for the cost per vehicle mile.

The main effect of simultaneous reductions in fare and spacing between stops in option 3 is to increase ridership relative to option 2. Operating costs remain the same due to no change in the number of buses; however, revenues decrease due to the reduction in fare. As a result, total deficit increases relative to option 2, but remains less than the base-case value. Option 3 is the most effective in terms of passengers per vehicle mile, passengers per vehicle hour, passengers per dollar of operating cost, and passenger miles per seat mile. Values of 19.458 passengers/driver-h and 73 675 passengers/vehicle are also the highest under this option.

In general, all three options offer significant improvements in most of the performance indicators. If a choice were to be made, it would have to be done with due regard to the relative importance of each performance measure and the magnitude of the trade-offs available.

CONCLUSION

A relatively simple and quick technique for analysis and assessment of the impacts of major operational policy variables has been presented in this paper. The technique involves identification of the impacts and use of simple mathematical relationships to measure them; particular emphasis is on performance. The applicability of the technique has been successfully demonstrated by a theoretical analysis of options for transit service improvement in a specific route of a case-study area.

The technique does not require an extensive amount of data collection effort; most of the information required is generally available from the records of a transit company. However, before it is applied, all of the assumptions made in the procedure must be considered and modified to suit a specific situation.

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Evaluation of Bus and Carpool Operations on the San Bernardino Freeway Express Busway

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The San Bernardino Freeway Express Busway, which runs eastward from downtown Los Angeles, is the most complete busway in the nation. It includes park-and-ride and on-line stations, feeder bus lines, outlying park-and-pool lots, and a supplemental contraflow bus lane in the central business district. Beginning in October 1976, carpools of three or more were permitted on this previously bus-only facility. During the mixed-mode operations, the number of carpools on the busway and freeway more than doubled, increasing by at least 800. These carpools were new and not caused by diversion from parallel roadways. Bus ridership was not noticeably affected until after a major fare increase. During the peak 1 h, the busway lane carries twice the number of people as does one adjacent freeway lane, but traffic still moves at 88 km/h (55 mph). Surveys were conducted among bus riders, busway carpoolers, and freeway users (busway nonusers). Most carpoolers said they would not be carpooling if they could not use the busway. Attitudes of most busway nonusers were positive; the busway is not controversial. There were no major safety or enforcement problems. The type of separation between busway and freeway was found to strongly affect safety and enforcement require-