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Bus Planning and Operations

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Bus Sketch Planning

WALTER CHERWONY AND MICHAEL G. FERRERI

A sketch-planning technique to quickly and inexpensively evaluate a large number of transit service alternatives is described. The application and results for the Birmingham, Alabama, metropolitan area are presented. The transit system is defined in terms of service type (e.g., express and local) and coverage area rather than typical bus-route-specific data. Travel markets are divided into three broad components: central business district (CBD), non-CBD, and community. For each service type, parameters are established that relate both bus system supply and costs. No modal-split model is used; instead, different capture rates or modal splits are assumed, and the effects on patronage, revenue, and cost are computed. By use of these simple measures, the feasibility of various test situations is evaluated and poorly performing test systems are deleted from further analysis. Since the sketch-planning approach does not rely on a calibrated modal-split model or network coding, it is easy to use and apply. The approach is also readily computerized, which provides a quick and inexpensive analytic planning tool.

The transit planning process is an iterative approach in that alternatives are formulated and evaluated and the results are used to identify additional alternatives that are then subsequently evaluated. After several iterations of this procedure, a preferred plan is identified and recommended for implementation. Because much of the testing phase relies on the use of computerized travel simulation tools, such as the Urban Mass Transportation Administration's Urban Transportation Planning System, the transit planning process is time consuming and requires considerable resources. At the same time, many transit agencies have been charged with the responsibility for exploring a full range of options, and this results in a greatly increased number of alternatives for testing. In large part, this reflects an increased interest in public transportation as a result of energy and environmental concerns. Many public officials want quick answers to the consequences of major shifts in the use of public transit. In essence, these queries represent a series of "what if" questions. For these reasons, there is a need for analytic techniques that can quickly and inexpensively examine a large number of schemes at a less detailed level. The objective of these procedures, which are termed sketch planning, is not to select a single plan but to provide timely information on the feasibility and desirability of a wide range of transit operations. In this way, promising alternatives are quickly and inexpensively identified for closer scrutiny. Alternatives that do not prove workable or desirable during the sketch-planning analysis can then be eliminated from further testing. The use of a two-tier testing process (sketch planning and detailed) provides a cost-effective method for examining a wide range of transit options. Furthermore, this approach permits resources to be concentrated on only those options that are preferred.

This paper presents a sketch-planning procedure called parametric analysis and its application to the testing of various bus options in the Birmingham, Alabama, metropolitan area.

OUTLINE OF THE METHODOLOGY

The analytic technique used in parametric analysis of bus options is similar to the initial steps of the traditional transportation planning process. Socioeconomic and land use data in conjunction with trip generation equations are used to estimate future trip productions and attractions. By use of a gravity model, these point estimates of travel demand are then converted into a matrix of total person trips within the region. Unlike the traditional planning process, the analysis is performed at a larger areal scale than zones (e.g., census tracts). The allocation of demand to the transit system is accomplished by establishing various transit capture rates rather than applying a modal-split model to obtain a single demand estimate. Another major difference of this sketch-planning approach is that the analysis is not network-specific. Thus, transit service is identified in terms of type of service (e.g., local and express bus) or coverage (e.g., present service territory or various options for expansion). The primary reason for this difference is that the objective of the parametric analysis is to test the consequences in terms of patronage, revenue, and costs of different modal-split percentages. This information from the sketch-planning process can then be used to determine feasible dimensions for a future bus plan. Another reason for not specifying bus lines is that route alignment will depend on the highway concepts proposed for testing at a later study stage.

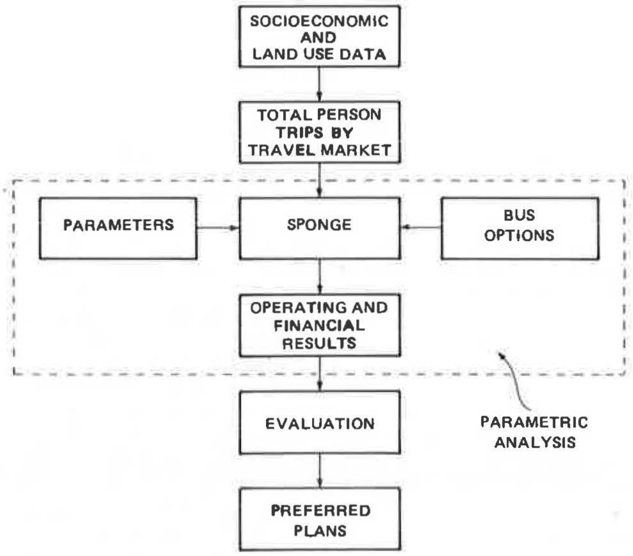
As noted above, the analysis is not network-specific and for this reason no transit assignment is performed. Instead, transit travel (capture rate times total person trips) is divided into three major travel-market components. The broad travel markets used in this analysis are (a) central business district (CBD) travel, which includes trips between the Birmingham core area and the remainder of the region; (b) non-CBD travel, which includes trips whose destinations lie outside the CBD and the community in which they originate; and (c) community travel, which is made up of trips both originating in and destined for the same community.

For each travel market, various bus options are proposed, and a set of parameters is formulated for each bus concept. The evaluation is then performed by using travel-market data and bus performance parameters to determine the patronage, revenue, and cost associated with each test condition.

To facilitate the parametric analysis, a computer program [Sketch Planning of Non-Guideway Electives (SPONGE)] was developed to perform the numerous calculations necessary for sketch planning. The data input includes trip information for each travel market and the parameters specified for each test condition. The output of the program is various key transit statistics, such as miles of service and peak vehicle requirements, as well as financial results and other efficiency measures.

As Figure 1 shows, the sketch-planning approach is not complex in that the input data are rather limited. Travel forecasts readily available from ongoing planning efforts are one key input item. The other two inputs consist of the bus options and the parameters to be used in the analysis. The bus options include the full range of transit services to be evaluated. The bus parameters are specified for each option and include such items as capture rate, vehicle costs, and average fare and unit operating costs. All data items are input to the SPONGE program, which generates the necessary output for evaluation results. Because of the simplicity of the process and the limited data requirements, quick turnaround of numerous test schemes is possible. Furthermore, the parameters can be varied as part of a sensitivity or risk analysis to assess the conse-

Figure 1. Sketch-planning process.



quences of different parameter values.

Travel Markets and Bus Options

As noted previously, the travel market was segmented into three primary markets: CBD, non-CBD, and community. The next step was the identification of the various bus options that could be used to satisfy the travel needs of the region. Seven bus operating strategies, ranging from fixed-route service to demand-responsive systems, were considered in the analysis. The bus options tested in the parametric analysis include the following:

1. Option 1, local bus, represents the continuation of existing bus service in that transit vehicles would operate on surface streets in mixed traffic. Buses would pick up and discharge passengers along their entire route, which would result in relatively low operating speeds.
2. With option 2, arterial express in mixed traffic, the collection and distribution function of the route would be restricted through either skip-stop service (buses only, stopping at every third, fourth, and fifth block) or express zones. The reduced accessibility of the route would produce operating speeds greater than those on local streets. Buses would still be subject to congestion delays.
3. Option 3, arterial express on exclusive lane, would be similar to the previous one in that patron pickups and discharges would be restricted. Buses would operate on an exclusive lane, which would result in less delay and higher operating speeds.
4. With option 4, freeway express in mixed traffic, buses would use a freeway for the line-haul portion of the route. Buses would exhibit the higher operating speeds associated with this roadway type, but vehicles would still be subject to congestion delays.
5. Option 5, freeway express (metered), calls for the operation of buses on a metered freeway on which the flow of traffic is controlled so as to assure a satisfactory volume-capacity ratio and high operating speeds for all vehicles on the highway facility. Ramps would provide for the metering of automobile traffic and priority access of transit vehicles.
6. Option 6, freeway express on exclusive lane, would establish an exclusive lane for buses that would expedite bus movements notwithstanding congestion in the other lanes.
7. The previous bus options are similar to the extent that buses would operate on a fixed-route alignment at an established headway. With option 7, dial-a-ride, buses would operate on a demand-responsive basis similar to taxicab operation. Unlike taxicab service, this bus option would permit group or shared riding.

It is apparent that all bus options are not suited for each of the three travel markets. For example, a dial-a-ride scheme for CBD travel is obviously impractical in view of the small vehicle used and the relatively large patronage potential, and so it was deleted from further consideration. A total of nine mode-market combinations were considered in the parametric analysis. The CBD travel market was analyzed for six different bus options: local bus, two arterial, and three freeway express bus concepts. The non-CBD travel was tested for a single bus plan, local bus. The dispersion of these types of trips would suggest that the various types of express bus service are not suited to this travel market. The community travel component was tested for both local bus and dial-a-ride. Because of the relatively short length of these trips, the various express bus options oriented to line-haul service were deleted from further consideration. Although the stratification of the travel market into three components and the specification of seven bus concepts represent a simplification, the information provided by the nine mode-market test conditions should provide sufficient information for guidance in the formulation of options for further detailed testing.

Parameter Identification

The next step in the analysis is the specification of parameters that influence transit performance. A single set of parameters was established for each bus option on the basis of available empirical data and subjective judgment. The parameters necessary for the bus testing, although substantial, are readily available for quantification. These parameters are listed below:

1. Capture rates of 1, 3, 5, 10, 15, 20, 25, 30, 50, 75, and 100 percent;
2. Annualization factor (equivalent weekdays per year) of 294;
3. Dial-a-ride operating statistics: vehicle miles per trip = -0.04 * trip density + 3.4 (vehicle miles per trip ≥ 1.0); speed = -0.25 * trip density + 22.5 (speed ≥ 10 miles/h);
4. Local and express bus operating statistics: passengers per mile = A + B * capture rate, where values of A and B are as given below:

Bus Option	A	B
1	1.970	0.065
2	1.379	0.045
3	1.379	0.045
4	0.788	0.026
5	0.788	0.026
6	0.788	0.026

5. Vehicle types and costs as follows:

Bus Option	Vehicle Type	Cost ($)	Life (years)
1	Bus	75 000	12
2	Bus	75 000	12
3	Bus	75 000	12
4	Bus	75 000	12

Bus Option	Vehicle Type	Cost ($)	Life (years)
5	Bus	75 000	12
6	Bus	75 000	12
7	Van	12 500	4

6. Average fare of $0.35, which reflects base, zone, and transfer charges as well as provisions for discount fares (e.g., senior citizen);

7. Interest rate of 8 percent;

8. Miles per peak vehicle = A + B * capture rate, where values of A and B are as given below:

Bus Option	A	B
1	32 700	150
2	33 700	140
3	35 300	124
4	37 600	101
5	39 200	85
6	40 000	77

9. Operating speeds as follows:

Bus Option	Speed (miles/h)
1	13.2
2	14.5
3	16.5
4	19.5
5	21.5
6	22.5

10. Operating cost: (a) local and express bus options = 9.342 * hours + 0.315 * miles + 3459 * peak vehicles; (b) dial-a-ride = 7.210 * hours + 0.230 * miles + 2243 * peak vehicles.

Many of the parameters, such as those for interest rate, annualization factor, and capture rate, have been established at the same value for all bus options. With the exception of the dial-a-ride service, which would rely on small vans, all options would use a conventional bus. The dial-a-ride operating statistics are related to trip density, which in turn is a function of the travel market and capture rate. Both vehicle miles per trip and speed are inversely proportional to trip density. Vehicle hours of operation and peak vehicle requirements are computed by applying the previous parameters to the test condition results.

The operating statistics for local and express bus are related to the assumed capture rate. Passengers per mile for all six fixed-route options is directly proportional to the capture rate, so that higher capture rates reflect increased efficiency. The value for passengers per mile is greater for local bus than for express operations since access to the transit system is possible over the entire route length. Similarly, express bus service on arterial streets exhibits superior performance in terms of passengers per mile than freeway service since access is greater. Obviously, buses that operate on freeways cannot pick up or discharge passengers for much of the route length. Patrons of this service typically ride to the end of the line (e.g., CBD) from their boarding location. In contrast, local bus service has the capacity of "turning over" seats, and the number of riders per mile is considerably greater.

Vehicle use, as measured by miles per peak vehicle, is directly proportional to the capture rate for all bus options. The higher values for express bus service are a function of the operating speed. Vehicles in express service can cover more miles during the service day than those that operate at lower speeds. The operating speeds for each bus option are the average for the entire route length--collection, distribution, and line-haul.

Two separate cost models were computed, one for more conventional bus service and another for the dial-a-ride option. The lower cost for dial-a-ride reflects the reduced unit cost with small vehicles as well as assumed reductions in driver labor rates that would accompany this concept.

SYSTEM EVALUATION

The intent of the nonguideway parametric analysis is not to select a single bus option for the Birmingham region in the year 2000. Instead, the goal at this stage of the analysis is to provide guidance in the formulation of alternatives for use in the detailed testing phase of the study. For this reason, one important consideration is the financial impact of each bus option for varying levels of ridership. Another issue addressed in the parametric analysis is the extent of the transit system in terms of route coverage. One plan would have the year-2000 bus system operating within the existing bus-service territory. Another plan would extend coverage to the entire region in the horizon year 2000. For purposes of simplification, only the results for the latter service area are reported in this paper.

As shown in Figure 2, the parametric analysis was performed for two different service-area plans and nine mode-market combinations and resulted in 18 unique analysis branches. Since the sketch-planning investigation was conducted for 11 assumed capture rates, a total of 198 test conditions were examined. Consistent with previous guideway analysis, all revenues and costs have been projected in 1976 dollars under the assumption of relative economic equilibrium.

Patronage

Patronage for the various bus options was computed by applying various capture rates to the total person-travel statistics. Approximately 2.5 million daily trips will be made within the region in the year 2000. The largest single travel market is non-CBD travel, which is the most difficult to serve by transit efficiently because of the dispersion of travel throughout the metropolitan area. Daily travel statistics are converted to annual patronage and revenue results for the expanded regional service area in Table 1.

Although the consequences of the full spectrum of capture rates are explored in parametric analysis, it would be helpful to identify a reasonable range of capture rates. Since the bus options vary from fixed-route to demand-responsive systems with an accompanying wide variation in speed, the reasonable range of capture rates would be from 1 to 10 percent. The daily patronage would range from 25 000 to 250 000 daily trips when service is provided throughout the entire region at the reasonable range of capture rates.

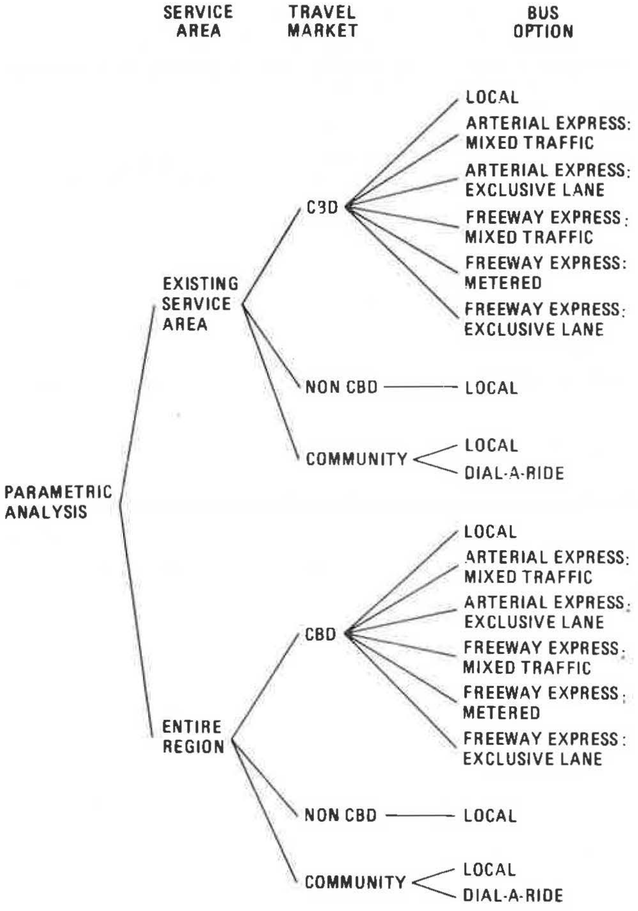
Revenue

Revenue projections for the parametric analysis were prepared for each service coverage option, travel market, and capture rate at a $0.35 fare. Annual revenue in the year 2000 with bus service extended throughout the region would be from $2.58 million at a 1 percent capture rate to $25.78 million when 1 in every 10 trips was made by public transportation.

Costs

Having established the revenue potential of various travel markets, the next step was to develop both capital and operating costs to provide bus service to satisfy this transit demand. Since no right-of-way or structures would be required to implement any of the bus options, the capital costs would only cover the cost of vehicles. As data given in Table 2 show, peak vehicle requirements vary significantly by travel market and bus option. For the CBD travel market, the local bus option would require the least number of vehicles at all capture rates. These results reflect the greater accessibility of the system under the local bus option than under the various express options, which more than offsets the impact of lower operating speeds. The express bus options would require more miles of service to be operated but would provide a higher quality of service because of the limited collection and distribution portion of the route and the higher operating speed. The community travel-market results are attributable to the smaller vehicle that would be operated with the dial-a-ride bus option. For all bus options, the number of vehicles required would increase at a slower pace than ridership because increased vehicle use would occur at higher capture rates.

Figure 2. Test conditions for parametric analysis.



The annualized costs for vehicles under each option and travel market, with the exception of the dial-a-ride option, were computed based on the same vehicle acquisition costs and economic life (see Table 3). For this reason, the relative capital cost of each option is the same as the number of vehicles. The dial-a-ride option at all capture rates would require considerably more vehicles to serve the community travel market than local bus, whereas the annual capital cost differential would be somewhat mitigated because of a less expensive vehicle. At a 10 percent capture rate, the dial-a-ride option would require nearly four times as many vehicles; however, the annual capital costs would only be about one-half greater.

Operating expenditures exceed capital outlays at all capture rates for each travel market and capture rate, which reflects the labor-intensive nature of bus operations. As data given in Table 4 show, the lowest operating cost for the CBD travel market would be obtained with the local bus options. These results are attributable to two countervailing impacts: (a) The bus option, with its greater accessibility, would require fewer miles to be operated to carry the same number of patrons, and (b) bus schemes with higher operating speeds would exhibit lower unit operating costs. The consequences of the first impact are greater than that attributable to speed. For this reason, the freeway express options are more costly than the arterial express schemes, which in turn have higher operating costs than the local service. Within each broad category of bus options (arterial and freeway express), the faster transit plans exhibit lower operating costs. The demand-responsive system, which affords point-to-point service, is substantially more expensive than local bus service in spite of the lower parameters used in the cost model for dial-a-ride.

The total annual costs for both capital and operating expenditures for each test condition are given in Table 5. The CBD travel market can be served at the least cost by local bus at all capture rates; this is consistent with the cost results described previously. The freeway express bus options are the most expensive schemes, and the arterial express option attains an intermediate position. The cost of

Table 1. Annual patronage and revenue by travel market.

Capture Rate (%)	Patronage (000 000s)				Revenue[a] ($000 000s)			
	CBD	Non-CBD	Community	Total	CBD	Non-CBD	Community	Total
1	2.11	4.40	0.86	7.37	0.74	1.54	0.30	2.58
3	6.33	13.19	2.58	22.10	2.22	4.61	0.90	7.73
5	10.55	21.98	4.30	36.83	3.70	7.69	1.50	12.89
10	21.11	43.95	8.60	73.66	7.39	15.38	3.01	25.78
15	31.67	65.93	12.89	110.49	11.08	23.07	4.52	38.67
20	42.23	87.90	17.19	147.32	14.78	30.76	6.02	51.56
25	52.78	109.88	21.49	184.15	18.47	38.46	7.52	64.45
30	63.34	131.85	25.79	220.98	22.17	46.15	9.02	77.34
50	105.56	219.75	42.99	368.30	36.95	76.91	15.04	128.90
75	158.34	329.63	64.47	552.44	55.42	115.37	22.57	193.36
100	211.12	439.50	85.97	736.59	73.89	153.83	30.09	257.81

[a] Based on average fare of $0.35.

providing bus service at each capture rate is generally directly proportional to the quality of service offered. The non-CBD travel market served by the local bus option would require relatively substantial outlays, but the cost would not increase at the same pace as ridership at increasing values of modal split. This is attributable to the higher efficiency and use of transit vehicles with increasing system demand. The community travel market is served at the lowest cost by local bus service at all capture rates. The dial-a-ride option provides door-to-door service and incurs substantially higher costs. In fact, the performance of dial-a-ride costs diminishes with increasing capture rates. For example, the cost of the dial-a-ride system at a 10 percent capture rate is approximately double the total cost for local bus, and at a 100 percent market share the dial-a-ride scheme is about eight times as

Table 2. Peak vehicle requirements by travel market.

	No. of Vehicles								
	CBD								
		Arterial Express		Freeway Express				Community	
Capture Rate (%)	Local	Mixed Traffic	Exclusive Lane	Mixed Traffic	Metered	Exclusive Lane	Non-CBD, Local	Local	Dial-a-Ride
1	32	44	42	69	67	65	66	13	132
3	89	123	118	193	186	182	184	36	185
5	138	192	184	302	291	285	287	56	245
10	236	329	316	522	503	495	491	96	393
15	308	431	415	688	665	654	641	126	548
20	362	508	491	815	790	778	753	148	701
25	403	567	549	915	889	876	839	165	856
30	435	613	595	995	968	955	905	177	1000
50	504	715	701	1186	1164	1153	1048	205	1599
75	527	754	747	1281	1269	1264	1069	215	2309
100	523	753	753	1307	1307	1307	1088	213	3022

Table 3. Annual capital cost by travel market.

	Cost ($000 000s)								
	CBD								
		Arterial Express		Freeway Express				Community	
Capture Rate (%)	Local	Mixed Traffic	Exclusive Lane	Mixed Traffic	Metered	Exclusive Lane	Non-CBD, Local	Local	Dial-a-Ride
1	0.32	0.44	0.42	0.69	0.67	0.65	0.66	0.13	0.50
3	0.89	1.22	1.77	1.92	1.85	1.81	1.83	0.36	0.70
5	1.37	1.91	1.83	3.01	2.90	2.84	2.86	0.56	0.92
10	2.35	3.27	3.14	5.20	5.01	4.93	4.89	0.96	1.48
15	3.07	4.29	4.13	6.85	6.62	6.51	6.38	1.25	2.07
20	3.60	5.06	4.89	8.11	7.86	7.74	7.49	1.47	2.65
25	4.01	5.64	5.46	9.11	8.85	8.72	8.35	1.64	3.23
30	4.33	6.10	5.92	9.90	9.63	9.50	9.01	1.76	3.77
50	5.02	7.12	6.98	11.80	11.58	11.47	10.43	2.04	6.03
75	5.24	7.50	7.43	12.75	12.63	12.58	10.91	2.14	8.71
100	5.20	7.49	7.49	13.01	13.01	13.01	10.83	2.12	11.41

Table 4. Annual operating cost by travel market.

	Cost ($000 000s)								
	CBD								
		Arterial Express		Freeway Express				Community	
Capture Rate (%)	Local	Mixed Traffic	Exclusive Lane	Mixed Traffic	Metered	Exclusive Lane	Non-CBD, Local	Local	Dial-a-Ride
1	1.17	1.57	1.45	2.30	2.18	2.12	2.44	0.48	1.56
3	3.30	4.44	4.09	6.48	6.13	5.97	6.87	1.34	3.73
5	5.18	6.98	6.44	10.18	9.63	9.38	10.79	2.11	5.84
10	9.06	12.21	11.26	17.80	16.84	16.42	18.85	3.69	10.74
15	12.06	16.28	15.02	23.73	22.45	21.89	25.11	4.91	15.46
20	14.46	19.53	18.02	28.45	26.93	26.26	30.10	5.88	20.17
25	16.41	22.18	20.47	32.31	30.58	29.83	34.16	6.69	24.82
30	18.03	24.38	22.51	35.52	33.62	32.80	37.53	7.34	29.36
50	22.42	30.38	28.06	44.25	41.92	40.90	46.68	9.13	47.11
75	25.48	34.56	31.93	50.35	47.73	46.60	53.04	10.38	68.37
100	27.30	37.05	34.25	54.00	51.23	50.02	56.83	11.12	89.77

Table 5. Total annual cost by travel market.

		Cost ($000 000s)								
		CBD								
			Arterial Express		Freeway Express				Community	
Capture Rate (%)	Cost Category	Local	Mixed Traffic	Exclusive Lane	Mixed Traffic	Metered	Exclusive Lane	Non-CBD, Local	Local	Dial-a-Ride
1	Capital	0.32	0.44	0.42	0.69	0.67	0.65	0.66	0.13	0.50
	Operating	1.17	1.57	1.45	2.30	2.18	2.12	2.14	0.48	1.56
	Total	1.49	2.01	1.87	2.99	2.85	2.77	3.10	0.61	2.06
3	Capital	0.89	1.22	1.17	1.92	1.85	1.81	1.83	0.36	0.70
	Operating	3.30	4.44	4.09	6.48	6.13	5.97	6.87	1.34	3.73
	Total	4.19	5.66	5.26	8.40	7.98	7.78	8.70	1.70	4.43
5	Capital	1.37	1.91	1.83	3.01	2.90	2.84	2.86	0.56	0.92
	Operating	5.18	6.98	6.44	10.18	9.63	9.38	10.79	2.11	5.84
	Total	6.55	8.89	8.27	13.19	12.53	12.22	13.65	2.67	6.76
10	Capital	2.35	3.27	3.14	5.20	5.01	4.93	4.89	0.96	1.48
	Operating	9.06	12.21	11.26	17.80	16.84	16.42	18.85	3.69	10.74
	Total	11.41	15.48	14.40	23.00	21.85	21.35	23.74	4.65	12.22
15	Capital	3.07	4.29	4.13	6.85	6.62	6.51	6.38	1.25	2.07
	Operating	12.06	16.28	15.02	23.73	22.45	21.89	25.11	4.91	15.46
	Total	15.13	20.57	19.15	30.58	29.07	28.40	31.49	6.16	17.53
20	Capital	3.60	5.06	4.89	8.11	7.86	7.74	7.49	1.47	2.65
	Operating	14.46	19.53	18.02	28.45	26.93	26.26	30.10	5.89	20.17
	Total	18.06	24.59	22.91	36.56	34.79	34.00	37.59	7.36	22.82
25	Capital	4.01	5.64	5.46	9.11	8.85	8.72	8.35	1.64	3.23
	Operating	16.41	22.18	20.47	32.31	30.58	29.83	34.16	6.69	24.82
	Total	20.42	27.82	25.93	41.42	39.43	38.55	42.51	8.33	28.05
30	Capital	4.33	6.10	5.92	9.90	9.63	9.50	9.01	1.76	3.77
	Operating	18.03	24.38	22.51	35.52	33.62	32.80	37.53	7.34	29.36
	Total	22.36	30.48	28.43	45.42	43.25	42.30	46.54	9.10	33.12
50	Capital	5.02	7.12	6.98	11.80	11.58	11.47	10.43	2.04	6.03
	Operating	22.42	30.38	28.06	44.25	41.92	40.90	46.68	9.13	47.11
	Total	27.44	37.50	35.04	56.05	53.50	52.37	57.11	11.17	53.14
75	Capital	5.24	7.50	7.43	12.75	12.63	12.58	10.91	2.14	8.71
	Operating	25.48	34.56	31.93	50.35	47.73	46.60	53.04	10.38	68.37
	Total	30.72	42.06	39.36	63.10	60.36	59.18	63.95	12.52	77.08
100	Capital	5.20	7.49	7.49	13.01	13.01	13.01	10.83	2.12	11.41
	Operating	27.30	37.05	34.25	54.00	51.23	50.02	56.83	11.12	89.77
	Total	32.50	44.54	41.74	67.01	64.24	63.03	67.66	13.24	101.18

costly as local bus service. Obviously, small-vehicle transit service is not designed to accommodate relatively large transit volumes.

Subsidy Requirements

Decisions regarding the amount of transit service provided in an area should not be governed strictly by the subsidy required to support such service. However, there are limitations on the funds available to underwrite the cost of public transportation. For this reason, both the operating margin and the total margin for each bus option and travel market were examined. This information will provide necessary information on the system dimensions for further detailed testing.

For the CBD travel market and service operated within the existing coverage area, the local bus option would cover operating expenses from the farebox at about a 20 percent capture rate (see Figure 3). The arterial express options would require subsidy until about a 30-40 percent market share is attained. With the more expensive freeway express services, approximately three of every four CBD trips would have to be made by transit to cover operating expenditures. The non-CBD travel market would require subsidy at all reasonable ranges of modal split (1-10 percent). Similar results are obtained for the local bus option serving community desires. The small-vehicle dial-a-ride system would never attain "break-even" operations (Figure 3).

When total costs including capital outlays are compared with farebox revenue, the subsidy requirements increase substantially. As Figure 4 shows, the market share for break-even operations is higher and the deficits incurred are larger. Some caution should be exercised in reviewing the relative financial performance of each bus option, since the transit patronage potential of each bus concept varies. For example, local bus service for the CBD travel market might only capture a 1 percent market share whereas the most costly metered freeway option could attract 10 percent of all trips.

Results

As noted earlier, the intent of the parameteric analysis was not to delineate specific route alignments and frequencies but rather to provide guidance in system dimensions and which surface bus options warrant further scrutiny. Obviously, future test networks will depend substantially on proposed highway plans and their ability to accommodate traffic. For the CBD travel market, a bus system composed of local service to those areas adjacent to the core area and express service in the outlying areas appears a feasible plan. The exact type of express service will depend on the type of available roadways. The penetration of the bus system beyond the current service area should be limited to those areas where concentrations of development will occur in the year 2000. The substantial increase in the total deficit with expansion of service coverage throughout the region would confirm the need for

Figure 3. Travel-market break-even capture rates: operating margin.

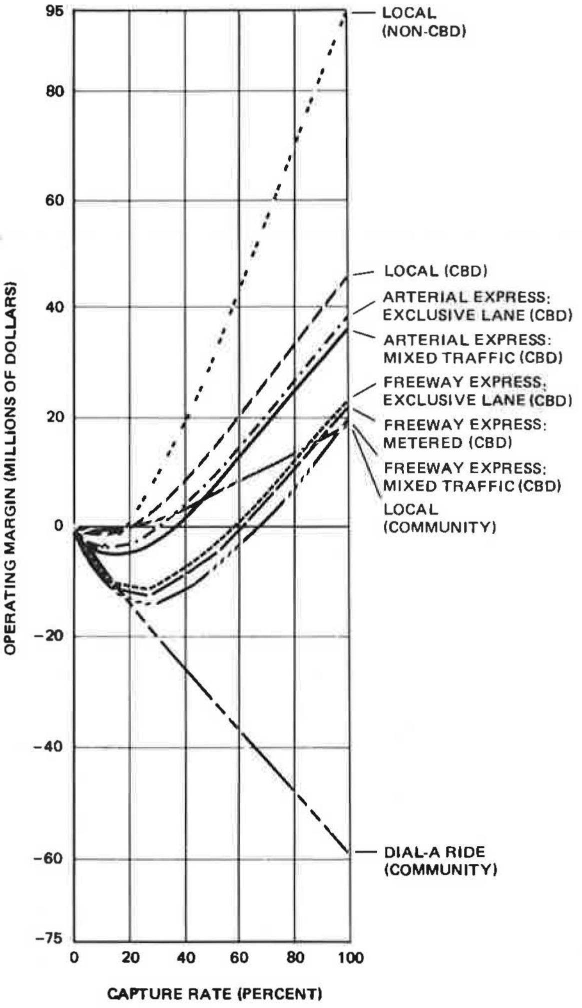
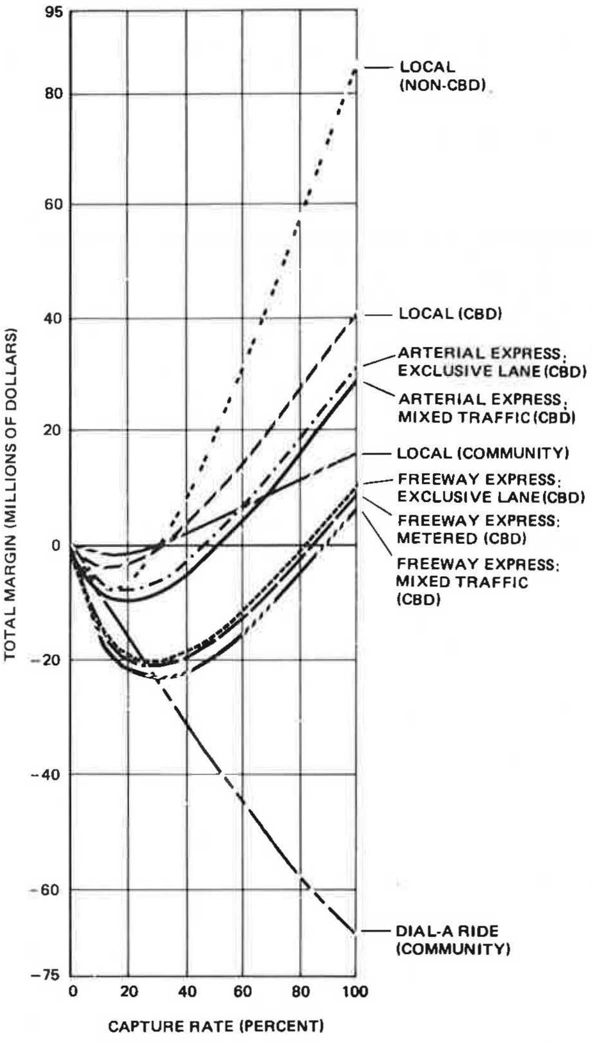


Figure 4. Travel-market break-even capture rates: total margin.



limiting the extent of new service areas. Park-and-ride lots at the periphery of the existing service area might enable some travelers from the more distant portions of the region to use public transportation. The non-CBD travel market can best be served by local bus operations, which ensure the greatest accessibility for the least cost. The dispersion of the travel demand makes it difficult to provide other types of bus service. For this reason, only the local bus option was examined in the parametric analysis. The results of the sketch planning clearly indicate that a dial-a-ride system serving community travel desires is not a financially feasible bus option and should be subjected to detailed testing only if local policies are financially supportive of such service concepts.

CONCLUSIONS

The analysis in Birmingham provides useful guidance in the formulation of preferred bus plans for detailed testing. Although the results represent only a single case, certain conclusions can be drawn about parametric analysis:

1. Because of the need for evaluating a broad range of transit options, the use of a two-tier testing process (sketch planning and detailed) appears appropriate.
2. Since parametric analysis does not rely on a modal-split model but assumes various capture rates, it permits the evaluation of alternatives to proceed concurrently with model calibration.
3. By not requiring network-specific information and relying on broad definitions of service territory and bus service type, transit planning can proceed independently of the highway network analysis.
4. Parametric analysis represents a simple and inexpensive technique for defining the dimensions of feasible bus options for detailed testing.
5. The parametric sketch-planning technique lends itself to sensitivity analysis where the values of parameters can be varied to test their implications on system performance.
6. Because parametric analysis is readily adaptable to computer processing, it represents a simple, quick, and inexpensive transit planning tool.

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Estimating the Contribution of Various Factors to Variations in Bus Passenger Loads at a Point

ROBERT M. SHANTEAU

A procedure for estimating the relative contribution of various factors to the variation of passenger loads on buses at a point is described. These factors include unequal bus headways and the uncertainty in the number of passengers to arrive in a given time interval. Since overcrowding is undesirable, for a given passenger flow a bus company must use more buses if the variation of loads between buses is large than if it is small. It is assumed that bus arrivals are either so frequent or so unpredictable that passenger arrivals are independent of bus arrivals. It is also assumed that bus headway does not change much over a typical passenger-trip length. Data are presented to show that, in the typical case, unequal bus headways contribute far more to variations of passenger loads on buses at a point than all other factors combined. It is rare that headways are so well controlled that their contribution becomes comparable with that of other factors. Where headways are poorly controlled, the public would most likely benefit from investments in headway-control strategies. In principle, the cost of controlling headways can be balanced against the benefits to find an optimal level of control.

The number of buses an urban transit agency must provide on a busy line is usually determined by the peak passenger flow past the maximum load point. Most often, the objective of the bus company is to use the fewest number of buses while still providing an acceptable level of service, where level of service is defined in terms of overcrowding and/or passenger waiting time.

Overcrowding is undesirable because (a) it causes discomfort and inconvenience to the passengers and (b) it makes circulation within the bus difficult and thus causes the bus to spend more time loading and unloading. In this paper, passenger waiting time is not used as a measure of performance. Instead, passenger loads are used because the bus company itself is mostly concerned with overloading.

Most bus companies try to provide some excess capacity to compensate for variations in loads that occur from day to day. These variations are caused by the stochastic nature of passenger arrivals and by unequal headways (elapsed time between buses). It was recognized as early as 1916 (1, p. 156) that unequal headways can be a major cause of variations in passenger loads.

Since fewer buses are needed on a line for which variations in loads are small than on one for which they are large, it is usually to the economic advantage of the bus company to use a control strategy that attempts to equalize headways (2). However, because traffic conditions and passenger stops cause variations in the travel times of buses, it is difficult to prevent deterioration in the regularity of headways (3). It is useful for the bus company to know what improvements in variations of loads it can expect from a range of control strategies so it can properly allocate its resources between vehicles and control.

PROBLEM STATEMENT

The practitioner is faced with the problem of how to evaluate various strategies without actually implementing them. In this paper, it is assumed that the future is sufficiently like the past that we can predict what would happen under different strategies in the future by analyzing data collected in the past. Basically, we want to relate the load on a bus to its headway in such a way that we can predict its load for different headways but for the same general passenger arrival pattern. First, however, we must set up a structure for the problem in which we can carefully state our assumptions.

ANALYSIS

Bus Trajectories and Passenger Arrivals

Suppose, for a particular day in the past, we plotted the time of arrival, origin stop, and destination stop of every passenger on the line on a time-space diagram, as shown in Figure 1. Here, the x's represent passenger arrivals and the subscripts the destination stop. Multiple subscripts mean that several people arrived at a stop at the same time. On the same diagram, we also plot the trajectory of each bus.

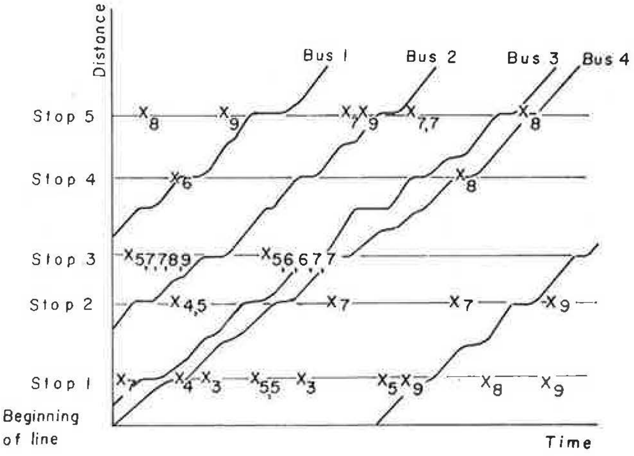
Usually, when a bus stops, it picks up all passengers who have arrived since the last bus left. For instance, in Figure 1, bus 3 picks up two passengers at stop 2, one each destined for stops 4 and 5. Assume that each bus always has room for all passengers waiting for it. Then the load on a bus at a particular point is the number of people who have arrived between that bus's trajectory and the previous one's and who desire to travel beyond that point. Passengers who got off prior to that point or get on after it are irrelevant. For instance, bus 3 is carrying seven passengers as it leaves stop 5. Note that, where bus drivers refuse passengers because their buses are already too full, the actual load may not match precisely the load that we have constructed. Note also that only departure times from stops are relevant and that the details of the trajectories between stops can be ignored.

Assumptions

Suppose that passengers' arrival times, origins, and destinations in no way depend on buses' departure times or on the strategy being used. That is, in Figure 1, if the buses had arrived at different times, the location of the x's and the subscripts would not change. This would happen, for instance, if buses arrived either so frequently or so unpredictably that passengers did not check the time before leaving for their stop. Then if we were to hypothesize a different set of trajectories for the buses, we could still easily construct the load each bus would have carried.

One difficulty with the procedure presented so far is that we need to know the passenger arrival times and the bus departure times at every stop. Suppose that bus trajectories are parallel or, in particular, that the time between a bus's departure at one stop and its departure at the next is the same for every bus (but not necessarily the same at every stop). If we now observe the departure times of all buses at one stop, we know the departure times of all buses at all stops. Essentially, we have assumed that a bus's headway does not change significantly over a distance comparable to the length of an average passenger trip. This allows the headway to change slowly. On a well-controlled bus line the headways do in fact change slowly.

Figure 1. Time-space diagram of a bus line.



This assumption also makes the description of passenger arrivals easier. In particular, it implies that the bus travel time from any point x to the point in question, x_0, is fixed. Let us call this travel time $\tau(x,x_0)$. Suppose we observe two passengers, one who arrives at stop x at time t and another who arrives at stop x_0 at time $t + \tau(x,x_0)$. Because bus trajectories are parallel and the arrival time of both passengers is the same relative to a given trajectory, both passengers catch the same bus. For our purposes, the two passengers are equivalent, and we can replace the original arrival process by an equivalent one at x_0 for which the arrival time of a passenger at x is shifted by $\tau(x,x_0)$. (Note that passengers who alight before the bus reaches x_0 are ignored.)

If we know the passenger arrival times for the equivalent process, then for any set of bus departure times from x_0 we could construct the loads on the buses at x_0. This procedure, however, still depends on the exact bus departure times (as opposed to simply the headways), since, for instance, the average rate of passenger arrivals might change over time and the loads on two buses with the same headway might be different. Let us assume that passenger arrivals are stationary, so that their average arrival rate is consistent. (The extension to nonstationary arrivals requires only that a headway be replaced with the time necessary to pick up a given number of passengers.) Then the expected load on a bus is simply proportional to its headway. That is, if $L|H = h$ is the random variable associated with the load on buses that have a headway h, then the expected value (or average) of the loads on these buses should be

$$E(L|H = h) = mh \tag{1}$$

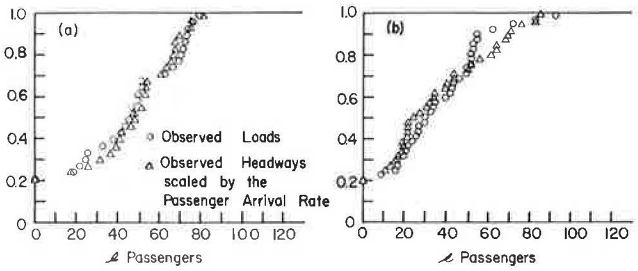
where m is the average passenger arrival rate. Because of the uncertainty in the number of passengers to arrive during a headway h (which is here called the uncertainty in passenger arrivals), the load on a bus with headway h will vary about mh.

Similarly, the average load over all buses, regardless of headway, is

$$E(L) = mE(H) \tag{2}$$

Because of unequal headways, uncertainty in passenger arrivals, and perhaps other factors, the load on an individual bus will vary about this mean. Suppose for the moment that only unequal headways contribute to the variability of loads on buses--i.e., passengers arrive in a steady stream. Then a bus with headway h would carry exactly mh passengers. If we were to plot the distribution of loads under this supposition and compare it with the distribution of actual observed loads, then any difference observed would be caused by factors other than unequal headways.

Figure 2. Comparison of actual load distribution with distribution of observed headways scaled by the passenger arrival rate: (a) 7:55-8:30 a.m. and (b) 8:45-9:30 a.m.



Example

Figure 2 shows a comparison such as that proposed above for data gathered for two different time periods on a bus line in Oakland and Berkeley, California. [The data were collected in November 1977 at the maximum load point of the northbound 51 line of Alameda-Contra Costa County (AC) Transit. This load point is downstream from a transfer point of the Bay Area Rapid Transit system.] The details of the data collection are given elsewhere (4). Basically, loads and headways of buses at the maximum load point were observed during two time periods when the passenger arrival rate was nearly constant. In this case, the maximum load point was downstream from a rapid transit station and any difference between the two distributions represents the effect not only of the uncertainty in the arrival of bus passengers but also of the uncertainty in the arrival of train passengers upstream of the transfer point and the uncertainty as to whether a bus picks up a batch of transfers from the rapid transit station at all.

That the distributions nearly coincide for each of the two time periods shows that the contribution of factors other than unequal bus headways to the variability of loads on buses is unimportant. In particular, uncertainty in passenger arrivals contributes little. Only if the headway distribution were considerably narrower than it was for these buses would uncertainty in passenger arrivals become significant. That is, unequal headways cause most of the variation in loads.

Variance Calculations

The phenomenon cited above can be quantified. If buses arrive either so frequently [i.e., at headways less than about 10 min (5)] or so unpredictably that passengers arrive independently of buses, then the variance of the load on a bus [Var(L)] is related to the variance of the headway of a bus [Var(H)] and a function characteristic of the passenger arrival process [r(h)], as follows (4):

$$\mathrm{Var}(L) = m^2\,\mathrm{Var}(H) + mE[Hr(H)] \tag{3}$$

Note that the variance and expected value are taken with respect to the headway distribution. In the second term, the expected value is taken of the function hr(h), where r(h) is the variance-to-mean

Figure 3. Typical shape of r(h) for AC Transit bus line in Oakland and Berkeley, California.

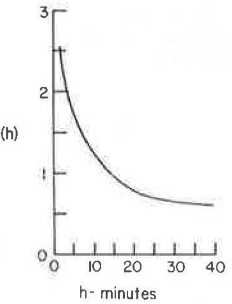


Table 1. Contributions of various factors to variance of load on a bus.

	Value of Contribution (passengers^2)	
Factor	7:55-8:30 a.m.	8:45-9:30 a.m.
Unequal bus headways	665	643
Uncertainty in the arrival of nontransferring passengers	63	50
Unequal rapid-transit-train headways	7	1
Uncertainty in the arrival of transferring passengers	14	2
Uncertainty that a bus picks up a batch	47	41
Total	796	737

ratio of the number of passengers to arrive in a time interval of length h, taken as a function of h. If passengers arrived in a Poisson process, for instance, then r(h) would be a constant, 1. It has been shown elsewhere (4) that, for values of h near a bus headway, r(h) is closer to 2 or 3. Further, r(h) is not constant. Its shape is typically as shown in Figure 3.

If there were no variability in headways, Var(H) would be zero; if there were no variability in the arrival of passengers, r(H) would be zero. Thus, the first term [m^2 Var(H)] is the contribution to load variance of unequal headways, and the second term is the contribution to load variance of uncertainty in passenger arrivals.

The equation analogous to Equation 3 for the data analyzed in Figure 2 is somewhat more complicated and is given elsewhere (4). Table 1 gives the numerical results for the various contributions. Again we see that unequal headways, represented by Var(H), cause most of the variability in the load on a bus. In this case, Var(L) $\simeq$ 750 passengers^2, and the standard deviation of the load is about ±27 passengers. That is, even though sufficient buses might be dispatched so that the average load is equal to the number of seats on a bus, an individual bus quite easily could carry as many as 27 standees or have 27 empty seats.

Coefficient of Variation of Bus Headways

The equation for Var(L) can be rewritten as follows:

$$\begin{aligned}\mathrm{Var}(L) &= C^2(H)\, m^2\, E^2(H) + mE[Hr(H)] \\ &= C^2(H)\, E^2(L) + mE[Hr(H)] \end{aligned} \quad (4)$$

where $C^2(H) = \mathrm{Var}(H)/E^2(H)$ and is the square of the coefficient of variation of the headway. Note that the calculation of E[Hr(H)] requires knowledge of r(h) as well as the complete headway distribution. For the purpose of approximation, let us assume that r(h) is a constant (even though we know it is not). Let this constant be r. Then $mE[Hr(H)] \simeq rmE(L)$, and

$$\mathrm{Var}(L) \simeq [C^2(H)\, E(L) + r]\, E(L) \quad (5)$$

Now the analysis of whether headways contribute more or less than passengers to the variation in loads comes down to whether $C^2(H)$ E(L) is large or small relative to r.

Rule of Thumb for Buses and Rapid Transit

The rule is this: If $C^2(H)$ E(L) is comparable to r, then headways and passengers contribute about equally to variations in the load on a bus. Note that this statement is also true if we take square roots: If C(H) $[E(L)]^{1/2}$ is comparable to $r^{1/2}$, then headways and passengers contribute about equally. For the two time periods analyzed above, C(H) was about 0.63 and 0.81, and E(L) was 41.4 and 32.0 passengers, respectively. Thus C(H) $[E(L)]^{1/2}$ was 4.05 and 4.58. As seen in Figure 3, r(h) is about 2-3 for headways of 2-6 min (the average headway during both periods was about 4 min), so we will let r be 2.5. Then $(2.5)^{1/2} \simeq 1.2$ is far less than C(H) $[E(L)]^{1/2}$ for either time period. Thus, we conclude that for these time periods unequal headways contribute far more to the variation in the load on a bus than does uncertainty in passenger arrivals.

In order for headways not to dominate, C(H) $[E(L)]^{1/2}$ would have to be about 1.2. For a full-sized bus, E(L) $\simeq$ 50, so C(H) would have to be about $[2.5/E(L)]^{1/2} \simeq 0.22$. Such a small variability in headways is rare, although not unknown. For instance, in a study of the Newcastle-upon-Tyne 33 route in December 1973 (6), C(H) at the Lonsdale Terrace stop was 0.57. Three years later, it was found to be 0.20.

The same analysis can be used for systems that have larger or smaller average passenger loads per vehicle. For instance, a rapid transit system might schedule its trains so that they carry about 1000 passengers. Then C(H) would have to be about 0.05 for headways and passengers to contribute equally to Var(L).

CONCLUSIONS

In effect, C(H) is a measure of the variability of the headway (specifically, the standard deviation) on a scale of the mean. This analysis shows that, for a bus line, if C(H) is above about 0.30, then unequal headways contribute almost exclusively to the variability of loads on buses. In this case, we would say that headways are poorly controlled. On the other hand, when C(H) is below about 0.3, unequal bus headways and uncertainty of passenger arrivals contribute about equally. In this case, headways are well controlled. In fact, it does little good to reduce C(H) below about 0.2 because under that value the uncertainty in passenger arrivals, over which the bus company has little control, starts to dominate.

When headways are poorly controlled, it might pay the bus company to invest in control strategies that reduce the variance in headways. If it can thus reduce the variance in loads, it can either use fewer buses and tolerate the same amount of overcrowding or it can reduce overcrowding and use the same number of buses. In the first case the bus company saves money, and in the second case the public receives better service. In either case, the public benefits (2).

This paper does not discuss the cause of unequal headways or the cost of controlling headways. It does illustrate that, once unequal headways occur, they are the dominant cause of variations in loads. A strategy to control headways, of course, must be based on a knowledge of why unequal headways occur. Once effective strategies are developed, then in principle their cost can be balanced against the benefits, as derived from this paper, to find the optimum level of control.

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REFERENCES

1. F.W. Doolittle. Studies in the Cost of Urban Transportation Service. American Electric Railway Assn., New York, 1916.
2. M. Abkowitz and others. Transit Service Reliability. Urban Mass Transportation Administration, U.S. Department of Transportation, Rept. UMTA-MA-06-0049-78-1, Dec. 1978.
3. G.F. Newell and R.B. Potts. Maintaining a Bus Schedule. Proc., 2nd Conference of the Australian Road Research Board, Vol. 2, 1964, pp. 388-393.
4. R.M. Shanteau. Analysis of an Urban Bus Line Serving a Rapid Transit Station. Institute of Transportation Studies, Univ. of California, Berkeley, Dissertation Series UCB-ITS-DS-79-3, Dec. 1979.
5. J.K. Jolliffe and T.P. Hutchinson. A Behavioral Explanation of the Association Between Bus and Passenger Arrivals at a Bus Stop. Transportation Science, Vol. 9, No. 3, 1975, pp. 248-282.
6. R.A. Chapman, H.E. Gault, and I.A. Jenkins. Factors Affecting the Operation of Urban Bus Routes. Transport Operations Research Group, Univ. of Newcastle-upon-Tyne, England, Res. Rept. 23, Dec. 1976.

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Proposed Approach to Determine Optimal Number, Size, and Location of Bus Garage Additions

THOMAS H. MAZE, SNEHAMAY KHASNABIS, KAILASH KAPUR, AND MANI S. POOLA

A proposed technique for determining the location, size, and number of new bus-garage additions is described. First, different cost components (nonrevenue transportation cost, operating cost, and construction cost) related to new garages (location, size, and number) are identified, and it is shown how most of the current techniques fail to consider the full ramifications of all of these cost elements. Second, an optimization model is presented that includes the full range of cost components that deserve consideration in decisions related to the number, location, and size of new garages. A case study is also presented in which the implications of the full range of cost components are tested on an actual fixed-facility problem. The case study uses the proposed technique in its most fundamental state. The analysis shows that some of the less visible but recurring nonrevenue cost components may significantly affect the total annual garage cost. On the other hand, the more prominent, one-time construction cost may be of marginal importance in the annual cost of the garages distributed over the life of the facility.

Determining the location, size, and number of new bus garages is a problem commonly faced by expanding transit agencies. However, little independent research has been devoted to developing a standard and accurate technique to determine the least-cost number, size, and location of garage facility expansions. The importance of the use of a standard and accurate technique for such purposes is twofold:

1. The addition of a new garage (or garages) represents a long-term commitment to a costly portion of the transit system. The following costs are quite important with respect to other system costs and can vary considerably in magnitude according to the prospective garage number, location, and size alternatives: (a) the costs of nonrevenue travel to and from work assignments, (b) the cost of operating the garage, and (c) the costs of new construction.
2. Locating and sizing a new bus garage is often one of the more controversial aspects of transit planning. Bus garages often occupy prime industrial sites but, because bus operators are public agencies, they do not enhance the local tax base. Furthermore, the movement of buses into and out of a garage often has a disrupting effect on traffic flow on adjacent arterials. For these reasons and others, proposals for new bus garages often meet with strong local opposition. Thus, it seems only prudent that the decision maker should have accurate information relative to the total cost ramifications to justify his or her choice of the location and size of a proposed garage or the number, location, and size of proposed garages.

This paper reviews methods that transit authorities have used to locate and size garage additions. The analysis techniques are described so that the reader can contrast existing techniques with the proposed technique. Next, a proposed technique is presented, along with a case study, to portray the possible cost saving resulting from its use. Finally, directions for future development of the proposed technique are outlined.

PROBLEM STATEMENT

The basic goal of all transit agencies is to provide transit service in the most equitable and cost-effective manner. The development of criteria defining the number, size, and location of fixed facilities constitutes a key element in the realization of this goal. A mislocated or improperly sized facility can, over a few years, account for millions of dollars in wasted funds. Conversely, the dollars saved by optimally locating and sizing these facilities can be more effectively used in other areas of system operations.

All of the characteristics of a garage scheme should be examined with regard to the entire transit system before the minimum-cost garage configuration is identified. Because it is possible to identify a broad array of combinations of the number, size, and location of proposed facilities, in conjunction with varied existing facilities, the determination of the least-cost combination becomes a complex problem. However, the amount of money that is inefficiently spent (accumulated over the life of a garage network) as a result of the nonoptimal number, location, and size of such facilities makes it necessary to find solutions to this complex problem.

A cost-minimization technique must do two things: (a) estimate the costs related to the number, size, and location of garages for all feasible options and (b) determine the cost-minimizing total garage network. Estimating the costs related to a garaging scheme is not a trivial task, and a review of existing methods will show that none of the existing techniques comprehensively estimate all related costs. There are three transit-system costs that depend on the number, size, and location of bus garages: (a) nonrevenue transportation costs, (b) garage operating costs, and (c) garage construction costs.

Nonrevenue transportation costs are composed of three elements: deadheading, relief, and spread-time costs.

1. Deadhead costs--The cost of the labor and vehicle mileage to bring buses from the garage to their in-revenue service points (pull-outs) and the cost of returning to the garage from the out-of-revenue service points (pull-ins) are the deadhead costs. A nonoptimal location of storage facilities may result in a significant amount of wasted funds in deadhead cost.
2. Relief cost--During the duration of a bus assignment (a block), a driver relief may be required. A relief may incur an additional transportation cost to the block for the garage under consideration. The relief cost assessed against the block is added to the deadhead transportation cost of a block.
3. Spread-time penalty--Spread-time penalty is the labor cost of having a driver scheduled for an 8-h split shift that does not begin and end within the period set in an agreement with the driver's union. A spread-time penalty is incurred when a driver works on a split shift that overlaps the specified period.

Spread-time-penalty savings are most evident when a suburban garage site is contrasted with an urban core site. This is because on suburban commuter routes the outer site has the advantage of being closer to morning in-revenue service points (pull-outs) and evening out-of-revenue service points (pull-ins). Because outer sites are closer to commuter route ends, a split shift can be served from the suburban facility and effectively used to cover both peaks with less elapsed time from beginning to end to the split shift, thereby decreasing the incidence of spread-time penalties.

The operating costs of a garage are the daily costs of servicing the buses, maintaining the facility, and allocating manpower and buses to blocks. The average operating cost per vehicle should show definite economies of scale that must be weighed against the diseconomies of scale of nonrevenue transportation costs (1).

Garage construction costs are the expenses of buying the land and of erecting and equipping the building. These costs depend on the size and number of the garages constructed. There are economies of scale in construction costs that must be weighed against the diseconomies of scale of nonrevenue transportation costs (1).

CURRENTLY USED TECHNIQUES

In reviewing existing methods used to size and locate garage additions, four basic techniques were identified: (a) the center-of-gravity method, (b) the rectilinear-distance method, (c) the scalar distance proxy method, and (d) the actual time and distance cost method. All of the identified techniques locate garages with respect only to minimizing deadheading. None consider garage number, size, and location costs other than with respect to nonrevenue transportation costs. The techniques reviewed and their associated drawbacks are discussed below.

Center-of-Gravity Method

The most common technique used to locate bus-garage additions is the center-of-gravity (CG) method. The CG method requires the user to identify all pull-in and pull-out points on a Cartesian coordinate system. Then the CG is found by determining the average point with respect to all pull-in and pull-out points in the vertical and the horizontal directions independently. The coordinate of the vertical and horizontal averages is assumed to be the location (the center of gravity) that will minimize deadhead travel distances (2). The CG method used to find the location of one garage within a system is expressed mathematically as follows:

$$x^* = \sum_{i=1} W_i a_i \Big/ \sum_{i=1}^{m} W_i \tag{1}$$

and

$$y^* = \sum_{i=1} W_i a_i \Big/ \sum_{i=1}^{m} W_i \tag{2}$$

where

a,b = coordinates of the pull-out and pull-in points,
W = number of bus movements to or from each pull-out or pull-in point,
x*,y* = coordinate of the center of gravity, and
i = a pull-out or pull-in point (1,2,...,m).

A multiple garage location problem can be solved by using the CG method and dividing the transit service area into a number of sectors within each of which a proposed garage is located. The CG of each sector is the proposed site of a garage under that sector scheme. The total vertical and horizontal deadhead distances are calculated from the Cartesian coordinate system and summed. Then another sector scheme is developed. The total vertical and horizontal distances from different iterations of sector schemes are compared, and the scheme with the least total deadhead distance is selected.

In summary, the CG method is fairly simple to apply and has received widespread application (2). However, some of its assumptions appear conceptually inaccurate. To illustrate the assumptions that do not appear conceptually correct, an allied problem is formulated:

$$\text{Minimize } F(x,y) = \sum_{i=1}^{m} W_i \left[(x-a_i)^2 + (y-b_i)^2\right] \tag{3}$$

$$\{[\partial F(x^*,y^*)/\partial x^*],\ [\partial F(x^*,y^*)/\partial y^*]\} = (0,0) \tag{4}$$

The partial derivatives of Equation 3 with respect to x and y, when set equal to zero, yield Equations 1 and 2, the solution to the CG problem. Thus, it is implied in the CG method that the resulting proposed garage location minimizes the weighted, squared Euclidean distance (straight-line distance) from the CG to all pull-out/pull-in points.

The CG method has received widespread application in the transit industry, primarily because of its simplicity. There are, however, a number of serious drawbacks to these techniques:

1. The CG method implies that the resulting proposed garage location minimizes the weighted squared Euclidean distance (straight-line distance) from the CG to all pull-out/pull-in points. Since it is not possible to travel through urban areas in a straight line, the use of Euclidean distance is clearly too simplistic.
2. The size and number of garages are determined independently of the analysis.
3. Because the objective of the method is to find the location for a garage addition that minimizes the weighted, squared Euclidean distance and not cost, it is impossible to treat other costs in the analysis (i.e., construction and operating cost).
4. Even if the CG method yields a location that will minimize deadheading, it does not account for the relief costs and spread-time penalties included in nonrevenue transportation costs.

Rectilinear-Distance Method

The rectilinear-distance method assumes that buses pull out and pull in along a Manhattan (Cartesian) grid system and that travel cost (as a function of distance) is the same throughout the grid (3). Thus, the location that will minimize the rectilinear distance between a garage and pull-out/pull-in points will minimize deadheading costs. The method, in its simplest form, can be expressed as follows:

$$\text{Minimize } F(x,y) = \sum_{i=1}^{m} W_i(|x - a_i| + |y - b_i|) \qquad (5)$$

Equation 5 can be restated as two separate optimizing problems:

$$\text{Minimize } F_1(x) = \sum_{i=1}^{m} W_i|x - a_i| \qquad (6)$$

and

$$F_2(y) = \sum_{i=1}^{m} W_i|y - b_i| \qquad (7)$$

One of the interesting properties of the solution to the rectilinear-distance problem is that the optimum vertical and horizontal coordinate location of the new facility is a median location (4). Because this property has a pictorial interpretation, the problem can be solved graphically. At least one transit operator was found to have located garages by solving the rectilinear-distance problem graphically (5). However, the rectilinear-distance problem is normally solved by picking a point (perhaps the CG) and stepping around the selected point until Equation 5 approaches its least value.

Some of the faults in the assumptions implicit in the rectilinear-distance method are the following:

1. The method is based on the computation of rectilinear distances. Although urban streets are often based on a grid system, the arterials that carry the bulk of traffic are radials and circumferentials.
2. The cost of deadheading is assumed to be proportional to rectilinear distance and equal in cost per unit of distance everywhere. Since travel costs vary depending on the kind of roadway, this assumption appears to be simplistic.
3. The rectilinear-distance method locates facilities with respect to deadhead travel only, a fault this method has in common with the CG method.

Scalar Distance Proxy Method

In the scalar distance proxy method, a scalar value is used for deadheading travel costs to candidate garage locations from pull-out/pull-in points instead of a coordinate system. Usually, a proxy for actual travel costs such as air-line distance or estimated travel time is used (6,7). This method sums the total of the proxy deadhead travel costs to candidate garage locations. The location with the smallest total cost is the best candidate.

This approach does not have the capability to distinguish between locations for originating bus assignments in a multifacility problem. Thus, this method can only treat a single-garage-location problem and assumes that the user knows which bus assignment will start from the additional facility. However, the method has the positive attribute of only examining sites that are identified for investigation rather than using all points in space for candidate sites, as is done with the CG and rectilinear-distance methods.

The only objective of the method is to minimize deadheading costs, and it does not examine other cost considerations. Thus, this technique is nearsighted in its treatment of garage size and location in relation to costs.

Actual Time and Distance Cost Method

The actual time and distance cost method allocates bus assignments to garages based on total deadheading and relief costs (8). Actual travel time and distance costs are obtained by using maps to measure the distances and estimate travel times. The bus assignments are relegated to the garage in a garaging scheme that possesses the least total relief and deadhead cost. Once all bus assignments are relegated to a garage, the number of vehicles assigned to a garage is checked to ensure that garage capacities are not exceeded. If a garage is assigned more vehicles than its capacity will allow, bus assignments are relegated to other garages based on the least difference in cost increase due to being relegated to a garage of second least cost. Once the capacities of all garages are satisfied, the total relief and deadheading costs of all bus assignments relegated to all garages are summed. Other garage schemes (different locations and numbers of garages) are subjected to the same process, and the least-total-cost garaging scheme is selected.

This technique has the advantage of using actual travel time and distance costs, but the method seems quite laborious when applied to a large network. In addition, because the method's only objective is to minimize deadheading costs and it does not examine other cost considerations, this technique is also nearsighted in its treatment of costs.

PROPOSED TECHNIQUE

A proposed technique to estimate transit system costs in relation to the number, size, and location of garages is presented below with illustrative examples. Later, the use of the proposed technique in a simplified form is demonstrated through a case study.

Nonrevenue Transportation Costs

Garage capital costs can be determined by estimating the construction costs of garages of varying sizes. Garage operating costs can be determined by estimating labor costs, supervisory employee costs, maintenance costs, and materials costs of garages of varying sizes. However, determining the nonrevenue transportation costs of multiple garages is quite complex. The means by which the components of nonrevenue transportation cost are accounted for is discussed below.

Before nonrevenue transportation costs are estimated, work rules regarding driver relief and spread times must be specified. The work rules are, to some degree, similar for all transit operators, but specific rules depend on the local union contract. The rules used in this description are those of the Minneapolis-St. Paul Metropolitan Transit Commission (MTC) that were in effect during 1976. However, the methodology may be restructured to fit the work rules of other operators.

Relief Costs

During specific work assignments (blocks), a driver relief may be required. Relief can sometimes be provided through the transit network. This requires that the driver be able to make connections from the garage to the relief point with only a 10- to 15-min bus ride and no transfers. If relief cannot be accomplished through the transit network, the relieving driver drives another bus to a point of interception with the block that requires relief. The drivers exchange vehicles, and the relieved driver returns to the garage.

Spread-Time Penalties

The MTC labor agreement specifies that, any time a driver works a split shift that overlaps a 10.5-h period, the overlapping time will be paid at 1.5 times the normal rate. In 1976, the average system wage rate, including an average quantity of spread-time penalties, was 19¢/min. If there was a spread-time penalty on a specific block, the average wage rate during the period of the penalty was 25¢/min. Spread-time penalty is paid at only 6¢/min above the average because fringe benefits, union dues, and other ancillary items are not paid at the accelerated rate when a spread-time penalty is incurred.

Cost Estimation Technique

To estimate the cost of various facilities, one must determine the nonrevenue transportation costs for operating all blocks out of all garages. In this way, the cost of any capacity of garages in any possible scheme can be assessed with respect to its transportation costs. A simplified two-garage example is presented here to demonstrate the use of the technique.

The solid line in Figure 1 is the path of route 1, and the dashed lines are the deadheading paths to the two garages, A and B. This example considers only the first three blocks on the route, which have the following pull-out and pull-in assignments:

Block	Pull-Out Point	Pull-In Point	Relief	Time Period
1	E	C	0	Morning
2	D	C	0	Morning
3	E	C	3	All day

Figure 1. Garage layout: route 1.

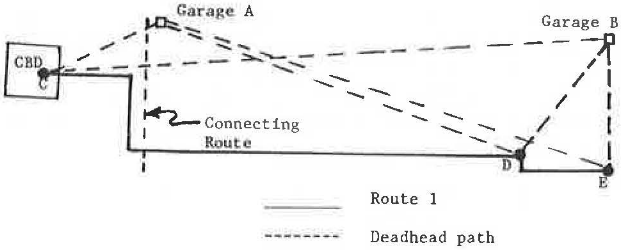

Table 1. Total nonrevenue transportation costs.

Garage	Block	Cost ($) Pull-Out	Pull-In	Relief	Total
A	1	16	4	0	20
	2	8	4	0	12
	3	16	4	0	20
B	1	2	17	0	19
	2	10	17	0	27
	3	2	17	12	31

In developing the cost estimates, only the total costs of the times and distances along the minimum paths between the garages and the pull-outs and pull-ins, respectively, are of concern. Thus, instead of dealing with miles or minutes of distance, the costing operation deals with dollars of distance, along the minimum-cost paths.

For example, the following costs were generated for the deadheading legs:

Garage to Point	Cost ($)
A to C	4
A to D	8
A to E	16
B to C	17
B to D	10
B to E	2

These costs were fabricated for this example, but they are indicative of actual estimated costs based on the MTC 1976 labor cost of 19¢/min and bus operating cost of 66¢/mile.

The nonrevenue transportation costs of blocks 1, 2, and 3 of route 1 are given in Table 1. The costs of blocks 1 and 2 are the sums of their deadheading-cost paths; however, the cost of block 3 is a little more difficult to calculate. Block 3 has three reliefs and, because a relief can be provided through the transit network from garage A, relief from garage A incurs no cost. There is no transit link between garage B and route 1. If block 3 were to come from garage B, relief would have to be provided by making three round trips to point E at a cost of $2/one-way trip or $12 for all three round trips. Therefore, a cost of $12 is assigned to block 3 coming from garage B, which makes it less costly to assign the block to garage A.

Spread Time

Any possible spread-time-penalty saving is usually attributable to servicing commuter runs from a suburban location. To determine the sensitivity of location to spread-time penalties, all commuter runs are assumed to bear such penalties. The totals for nonrevenue transportation costs are recalculated, and a comparison can be made to determine how important potential spread-time penalties are in relation to other costs.

Figure 2. Garage layout: route 13.

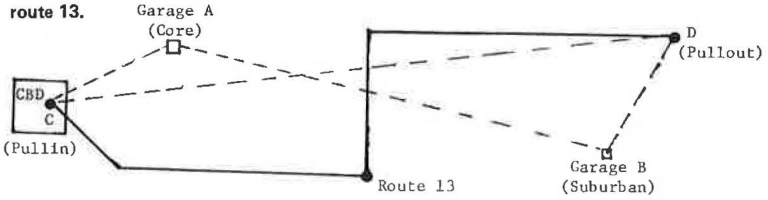

Table 2. Nonrevenue transportation costs with and without spread-time penalties.

Garage	Spread-Time Condition	Cost ($) Pull-Out	Pull-In	Relief	Total
A	With	21	4	0	25
	Without	18	4	0	22
B	With	10	14	0	24
	Without	9	14	0	23

An example (similar to the previous example but for a different route) is shown in Figure 2 to illustrate the checking of the sensitivity of costs to spread-time penalties. Spread-time penalties are assumed only on morning pull-outs and evening pull-ins; if one uses the MTC labor costs as an example, this increases labor costs from 19¢/min to 25¢/min on potential penalty legs. The deadheading costs corresponding to these two labor costs for the example shown in Figure 2 are given below:

Garage to Point	Deadheading Cost ($) At 19¢/min Labor Cost	At 25¢/min Labor Cost
A to C	4	5
A to D	18	21
B to C	14	16
B to D	9	10

Only one (morning) block of route 13 without a relief is necessary to illustrate how spread time is accounted for. Table 2 gives two nonrevenue transportation cost totals, one using straight-time labor costs and the other using spread-time labor penalties on the pull-out leg.

Based on straight time, the least-cost garage for the block in the example would be garage A, the core city site. If the block does bear a spread-time penalty, it should be assigned to the garage of least cost, garage B at the suburban site. It should be noted that, for every morning commuter block of this nature, there is a mirror-image evening commuter block that should also be assigned to the suburban site.

If the analyst is unsure whether this particular block will bear a spread-time penalty, to be conservative it can be assumed that the block will bear a spread-time penalty. Thus, the least-cost origin for the example is assumed to be the suburban site. However, when the total nonrevenue transportation cost is summed, the spread-time penalty should not be included. In the average MTC labor-cost figure, an average quantity of spread-time penalties was included and it should not be counted again. Therefore, spread-time penalties are only brought into the analysis to help in determining the least-cost block assignment to a garage.

The example shown here is the exception rather than the rule. Deadheading costs are the sum of travel-distance (66¢/mile) and time costs. The additional 6¢/min for spread-time penalties will generally have an insignificant effect on total nonrevenue transportation costs and on the final assignments of blocks to garages.

Distance and Time Cost

For all metropolitan planning areas, there exists a computerized highway network that is coded with average velocities and lengths of highway links. The mileage cost (66¢/mile) and the labor cost (19¢/mile) are applied to the highway network, and the Federal Highway Administration and Urban Mass Transportation Administration (UMTA) network programs will determine the minimum-cost paths and accumulate the costs from every network centroid to every other centroid. Centroids can be moved or created so that they are approximately located at every pull-in and pull-out point and at every possible garage location. In this way, one can determine the costs of traveling from every pull-in and pull-out point along the minimum-cost path to every existing or prospective garage point. The advantage of this methodology is that the transportation costs are not proxy measures but rather are the actual measured costs from every point of interest to every other point of interest. By using the distance and time costs derived from the computerized highway network, one can estimate the total actual nonrevenue transportation costs to serve all blocks from all garages.

Optimization

The objective of the optimization is to use estimates of garage capital and operating costs and nonrevenue transportation cost to select a garage scheme (including existing and proposed facilities) that minimizes the total cost. This is known as a location-allocation problem. The optimization must search through the feasible combinations of decision variables and select the combination that minimizes the system cost variables. There are three decision variables: (a) the size of each garage, (b) the location of each garage, and (c) the number of garages in the system. The optimization must minimize the following three system variables: (a) construction costs for all new facilities, (b) nonrevenue transportation costs, and (c) operating costs for the facilities.

The optimization problem is to

$$\text{Minimize total cost} = \sum_{j=1}^{m} \sum_{i=1}^{k} T_{ij}(n_{ij}) + \sum_{i=1}^{k} O_i(n_i) + \sum_{i=1}^{k} C_i(n_i) \qquad (8)$$

subject to

$$\sum_{i=1}^{k} n_i = N,$$

$$\sum_{i=1}^{m} n_{ij} = n_i, \text{ and}$$

$$n_i \geq 0,$$

where

m = total number of blocks assigned to garage i;

k = total number of garages;
j = pull-out/pull-in paired points of each block going to garage i;
T_{ij} = total matrix of nonrevenue transportation costs from pull-out/pull-in paired points j to garage i;
n_i = number of blocks allocated to garage i, $i = 1,\ldots,k$;
$O_i(n_i)$ = operating costs of garage i as a function of its size n_i (the number of blocks is converted to the quantity of buses needed to serve n_i blocks);
$C_i(n_i)$ = construction cost of garage i as a function of its size n_i (the number of blocks is converted to the quantity of buses needed to serve n_i blocks); and
N = total number of blocks assigned to all garages.

CASE STUDY

A case-study example has been developed by using the assumption that the number, size, and location of garages that minimize nonrevenue transportation costs also minimize total cost related to the number, size, and location of garages in the garaging scheme. It is recognized that this simplistic assumption disregards the effects of operating and

Figure 3. Location of bus garages in Minneapolis-St. Paul area.

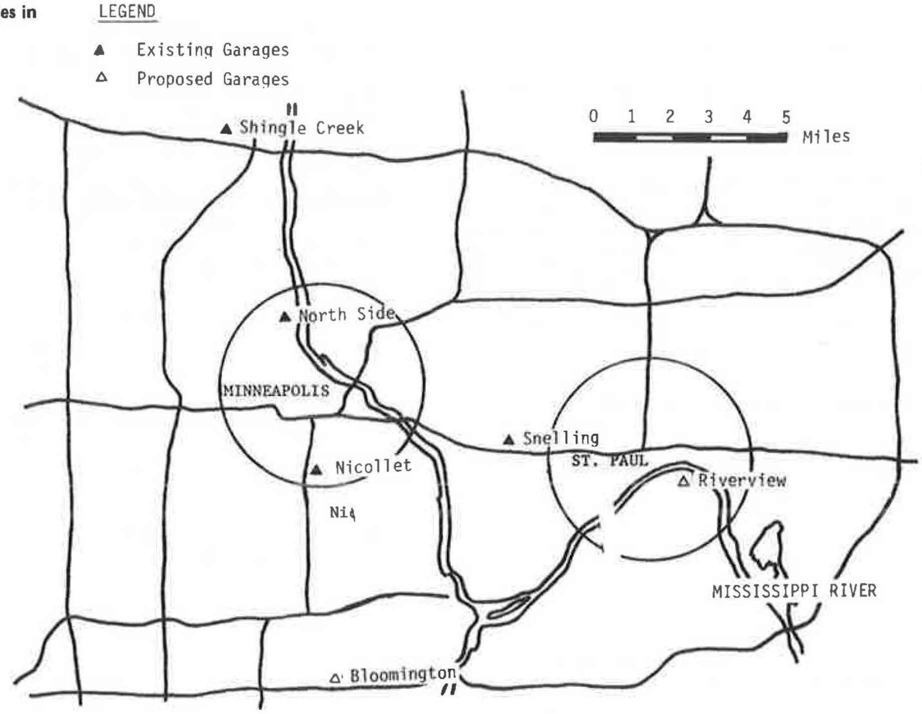

Table 3. Garage-related annual MTC system costs for alternative scenarios.

Garage	Peak Demand (no. of vehicles)	Capacity (no. of vehicles)	Cost ($)		
			Construction	Operating	Transportation
Existing MTC System					
Snelling	229	250	-	1 045 933	1 480 740
Nicollet	243	270	-	1 103 834	1 626 900
North Side	261	300	-	1 190 653	1 260 630
Shingle Creek	146	150	-	801 509	1 160 870
Total	879			4 141 929	5 529 140
Planned MTC System					
Bloomington[a]	165	200	283 824	899 245	1 472 620
Nicollet	243	270	-	1 103 834	1 421 580
Shingle Creek[b]	242	300	213 955	1 103 834	1 824 680
Snelling	229	250	-	1 045 955	1 480 740
Total	879		497 779	4 152 868	6 199 620
Recommended System					
Nicollet	243	270	-	1 103 834	1 626 900
North Side	261	300	-	1 190 653	1 243 230
Shingle Creek	116	150	-	703 774	986 870
Snelling	113	150	-	703 744	355 830
Riverview[a]	146		283 824	703 774	672 800
Total	879		283 824	4 405 809	4 885 630

Note: Amounts in 1976 dollars.

[a] New. [b] Expanded.

Table 4. Garage-related system costs for MTC projected 1985 transit network.

Garage	Peak Demand (no. of vehicles)	Capacity (no. of vehicles)	Cost ($)		
			Construction	Operating	Transportation
Planned MTC System (as of 1976)					
Bloomington[a]	270	300	372 716	1 190 653	2 855 920
Nicollet	243	270	-	1 103 834	1 531 490
Shingle Creek	242	270	213 955	1 103 834	2 027 970
Snelling	144	175	-	801 509	604 650
Riverview[a]	202	225	304 766	972 600	1 233 080
Total	1101		891 437	5 172 430	8 253 110
Recommended System					
Northside	261	300	-	1 190 653	1 350 750
Bloomington[a]	122	150	283 824	703 774	1 075 320
Nicollet	243	270	-	1 103 834	1 456 090
Shingle Creek	129	150	-	703 774	1 052 110
Snelling	144	175	0	801 509	609 950
Riverview[a]	202	225	304 766	972 600	1 233 080
Total	1101		588 590	5 476 144	6 777 300

Note: Amounts in 1976 dollars.

[a] New.

capital costs on the size, location, and number decision. However, this case study is meant to show the importance of having accurate information on costs related to garage number, size, and location.

Based on the above assumption, blocks are assigned to the garage that has the least nonrevenue transportation cost. Once all blocks are assigned a garage, the size of the garage necessary to serve all assigned blocks is determined. Then the three system cost components for each facility can be totaled and the total cost of the scheme determined. The same process is repeated for garage schemes with varied numbers of garages and at different locations. The results of various iterations of the process are compared, and the minimum-total-cost garage scheme is selected.

This demonstration is intended to show some of the possible payoffs of using the proposed technique (9). This application is quite limited in that it only examines the few sites the transit operator has subjectively selected and is in no way an exhaustive search of all possible sizes and locations of fixed facilities. This by no means serves as a plan for the operator's fixed-facility improvements and is only a demonstration.

The MTC operated three older bus garages--North Side, Snelling, and Nicollet--and a new facility at Shingle Creek (see Figure 3). The MTC had developed a facility expansion program that can be summarized as follows:

1. Increasing the capacity at Shingle Creek to 300 vehicles,
2. Building a 200-vehicle facility in Bloomington that would be increased to 300-vehicle capacity in the future,
3. Phasing out the North Side site, and
4. Building a garage in St. Paul at Riverview in the future.

The first step in the demonstration was to estimate the nonrevenue transportation costs of serving all bus assignments from all existing garages (Snelling, North Side, Shingle Creek, and Nicollet) and all proposed garage sites (Riverview and Bloomington). Nonrevenue transportation costs were calculated in the manner specified earlier. Estimates of operating and construction costs for garages of various sizes were taken from a 1975 MTC study (1). Different cost elements are presented in Table 3 for three alternative scenarios: (a) the existing MTC fixed facilities, (b) MTC's planned facilities, and (c) the recommended facility locations and sizes that resulted from this demonstration. Table 3 indicates that, based on the 1976 system, the MTC plan would cost approximately $1.18 million/year more than the existing garage system and $1.27 million/year more than the recommended system.

Table 4 gives costs of the proposed 1985 system under two scenarios: (a) MTC's planned facilities and (b) the recommended facility sizes and locations that resulted from this demonstration. A review of Table 4 shows that, based on the proposed 1985 transit network, the MTC plan would cost $1.48 million/year more than the recommended system.

In the analysis, a check of possible assignments of blocks to garages was made with respect to spread-time penalties. All blocks that could possibly have a spread-time penalty were assumed to bear one. As a result of this exercise, a total of 4 blocks out of well over 1500 were reassigned to a suburban location. Thus, in this case, spread time did not have a significant impact on the analysis.

This demonstration is limited to a few options and assumes that a garage number, size, and location scheme that minimizes nonrevenue transportation cost minimizes total costs. However, it is intended to show the significance of the costs that can be saved by using a simplified version of the proposed optimization.

CONCLUSIONS

The determination of the number, size, and location of bus-garage additions is a problem that must be treated with care, and the resulting choice should have an accurate and technically sound basis. Most of the currently used techniques do not use a comprehensive costs basis and, at the very least, they are founded on conceptually inaccurate assumptions. The survey of currently used methods presented in this paper clearly indicates that new methods need to be sought out.

This paper presents a method to be used to seek out a minimum-cost garage number, size, and location scheme from an exhaustive array of feasible combinations. As part of an UMTA-sponsored study at Wayne State University, we are currently in the process of developing a more comprehensive method for solving the garage location problem. The importance of the development of such a technique is portrayed in the MTC case study through the application of a simplified version of the technique. Further, the analysis shows that some of the less visible but recurring cost components (deadheading and relief costs) may significantly affect the total annual costs of a proposed garaging system. On the other hand, new construction costs, which may seem highly important during the earlier planning stage, may have marginal ramifications for total system costs when spread over the life of the project.

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The views expressed in this paper are ours and do not necessarily reflect those of UMTA or any other agency named or referenced in the paper.

REFERENCES

1. T.P. Collins. Optimum Garage Size Analysis. Metropolitan Transit Commission, Minneapolis-St. Paul, 1975.
2. W.C. Gilman and Company. Milwaukee Transit Facility Requirements. Milwaukee County, Milwaukee, WI, 1979.
3. Simpson and Curtin, Inc. A Five-Year Fixed Facilities Improvement Program for Southeastern Michigan. Southeastern Michigan Transportation Authority, Detroit, 1975.
4. D.L. Francis and J.A. White. Facility Layout and Location: An Analytical Approach. Prentice-Hall, Englewood Cliffs, NJ, 1974.
5. Third Metro Bus Garage Location Study: Summary. Denver Rapid Transit District, Denver, CO, 1976.
6. Luckett and Farley, Inc., and Schimpeler-Corradino Associates. TARC Garage-Office Facility: Location and Integration Analysis. Transit Authority of River City, Louisville, KY, 1976.
7. B.B. Balzer. Garage Location Studies: A Methodology. Transitions, ATE Management and Service Co., Cincinnati, Spring 1980.
8. F. Spielberg and M. Goldberg. Systematic Procedure for the Analysis of Bus Garage Locations. TRB, Transportation Research Record 746, 1980, pp. 39-42.
9. T.H. Maze. A Methodology for Locating and Sizing Transportation Dependent Facilities as Applied to Locating and Sizing Bus Garages for the Metropolitan Transit Commission, Twin Cities, Minnesota. Institute of Transportation Studies, Univ. of California, Berkeley, master's thesis, 1977.

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Abridgment

Practical Methodology for Determining Dynamic Changes in Bus Travel Time

AVISHAI CEDER

Research undertaken to develop and examine two methods of treating bus travel time—(a) measurement and (b) processing and analysis for planning needs—is reported. These methods are intended mainly for the scheduler responsible for scheduling buses to trips so as to take into account any dynamic changes in bus travel time. The motivation for the research comes from the existing system at Egged (the Israel National Bus Carrier), which uses a single mean value for bus travel time (for a given bus line) for all days of the year. The method chosen for data collection on bus travel time is based on the use of the tachograph, which is currently an integral part of bus equipment. The tachograph allows for a current report on departure and arrival times of trips through the turn of a special knob by the driver. In comparison with other information systems being tested today, the tachograph is simple and inexpensive to use. The accumulated data on bus travel time are transferred by use of a statistical method to calculate means and standard deviations for three cross sections: daily, weekly, and seasonal. The criteria for the statistical method are that it be simple, flexible, systematic, and practical so that the outcome will be compatible with the objective of planning work schedules for buses.

Egged (the Israel National Bus Carrier) operates a widespread geographic network of about 4000 lines. These lines are urban, suburban, regional, and intercity, with a vehicle fleet size of more than 5000 buses covering an average of 54 000 daily trips. The planning process for such a vast number of daily trips is clearly a complex and challenging undertaking.

One of the more crucial input elements in the planning process is bus travel time (BTT). This element depends on trip time (hour, day, week, season), number of passengers, and the habits of each individual driver. This paper describes a method implemented for Egged on how to measure and consider BTT, particularly from a practical viewpoint. Before demonstrating this method, however, let us represent the general planning process of a large-scale bus company and indicate how travel time affects this process.

The planning process is composed of five major components: (a) planning bus stops, (b) planning bus routes, (c) setting timetables, (d) scheduling buses to trips, and (e) assigning drivers. Since interrelations exist among the five components, it is desirable to analyze them simultaneously. If so, BTT would influence the whole planning process. However, the complexity of the system induces separate treatment for each component, a process in which the outcome of the treatment of one component is fed as an input into the next component. Consequently, the component that is directly affected by the dynamic changes in BTT is the procedure of scheduling buses to trips.

Recently, Egged has experimented with a fully optimal bus-scheduling algorithm (1) in an attempt to replace currently used manual planning procedures (60 schedulers using Gantt charts). However, because of the limitations of this algorithm, an approximate procedure incorporating a man-computer interface was requested. This man-machine interactive scheduling procedure has been developed but has not yet been fully implemented (2). This method allows for the inclusion of practical considerations that experienced schedulers may wish to introduce in the schedule.

IMPORTANCE OF BTT

Extensive investigation of BTT has been carried out for two main purposes: (a) to find applied methods and directions for reducing the mean travel time and (b) to simulate bus operations in order to achieve appropriate control strategies for the improvement of level of service.

The first purpose represents a clear advantage for both bus passengers (saving travel time) and the operator. The operator can either reduce fleet size, increase the frequency of service, or release more recovery time for drivers at the arrival end point. This purpose was also included in the framework used by the Transport Operations Research Group at the University of Newcastle-upon-Tyne, which conducted research on the operation of bus routes (3-5). The reduction of the mean value of BTT could be attributed to those actions that attempt to minimize the variation of sources of irregularity, including (a) different numbers of boarding passengers, (b) different passenger boarding times, (c) different travel times between bus stops, (d) the probability of buses stopping at stops, and (e) undisciplined departures from terminals.

The second purpose for using BTT is related to simulation studies. The simulation program usually serves as a tool for (a) evaluating planning control strategies (6,7) for such changes as bus stops, routes, and timetables and (b) evaluating operational control strategies for both off- and on-line systems (8,9) in order to avoid such conditions as bunching of buses, running behind schedule, and carrying an undesirable number of passengers. For example, one simulation study (9) found, as expected, that variability in BTT has an important effect on the reliability of bus service and can be reduced through priority operation and, in particular, through on-line control.

Nevertheless, these investigations were not planned to specifically address the component of scheduling buses to trips. The purpose of this paper is to present a simple method of both measuring and determining BTT so that the scheduler can use it in either a manual or an automatic (fully computerized) mode. At present, Egged schedulers obtain the mean value of BTT and refer to it on Gantt charts. The prime objective of the skilled scheduler is to minimize the required fleet size for a given fixed schedule. Unfortunately, because of the large number of daily trips made by Egged (54 000), the mean BTT is updated once a year, after a two-day period of observation. This mean BTT is used for all hours of a day, all days in a week, and all weeks in a year.

MEASUREMENT OF BTT WITH AN ELECTRONIC TACHOGRAPH

As previously stated, Egged operates about 4000 bus lines, each of which has a single mean value of BTT. Since BTT is a stochastic variable, it would be desirable, for planning purposes, to know the mean values mainly as a function for three types of cross sections: daily, weekly, and seasonal. Naturally, to obtain such information, a wide-ranging sample that covers all 4000 lines would be needed. To do this manually would require great resources, the costs of which would not be justified by the results to be obtained.

The tachograph is a well-known instrument developed nearly 50 years ago, mainly as a follow-up on driver behavior and to collect aggregate data on distance, time, and speed. The instrument is connected to the speedometer as data are delineated on a diagram chart. The chart turns at a standard pace, and three styluses register vehicle speed, the time the vehicle is stationary or in movement, and travel distance. There is the option of collecting additional data with a fourth stylus. The chart generally serves for a 24-h time period (for safety needs, it is possible for the chart to complete a turn in 20 min and then erase itself). There are also tachographs that allow for the use of seven charts for the week, which can be removed after that time.

Today, the tachograph is standard equipment on new buses. Of course, the advantages of the tachograph over other data-collecting instruments are that it is inexpensive and readily applicable to buses.

In a project carried out by Egged (10), a system for coordinating the characteristics of the tachograph in order to measure BTT was recommended. To do this, an additional capability must be added to the tachograph so that the driver can indicate the start and end of trips. The recommendations of the Egged project were applied, and Egged's latest order for 1150 Mercedes buses (which were to enter service during 1980) included the tachographs, which will also serve to measure BTT.

Of the 54 000 daily trips made by Egged buses, 36 000 are service trips, 14 000 are deadheading trips, and 4000 are special routine trips. In order to identify these trips, it was recommended that a special knob be installed on the tachograph that can be adjusted to the three different trip types. The direction of this knob should be made conspicuous to the driver (by eye-catching lettering or various colored lights), in order to ensure compatibility between the type of trip and the correct position of the knob.

An electronic tachograph designed for daily diagram charts of 24-h periods was chosen. Figure 1 shows an example of a tachograph diagram chart for 20 trips during a period from 3:30 a.m. to 8:00 p.m. Under the speed diagram (in the example, the speed range is up to 80 km/h, which is suited to urban buses, whereas for interurban buses the speed range is up to 125 km/h), there are indications for type of trip along the time horizon. The first trip is a short one, from the bus depot to the origin station (deadheading trip). The next is a special trip that returns as a deadheading trip. Then the service trips begin and among these are two special and two additional deadheading trips. Finally, there is a deadheading trip when the bus returns to the depot. The differences between the types of trips are indicated by bands of varying widths recorded along the time horizon on the diagram chart.

The processing of travel-time data can be carried out manually by coordinating it with the driver's work schedule (which trip was carried out at all times in relation to the plan). On the other hand, manual processing is suited for sample and ad hoc needs (a skilled worker can analyze a diagram chart

Figure 1. Diagram chart covering 20 trips from 3:30 a.m. to 8:00 p.m.

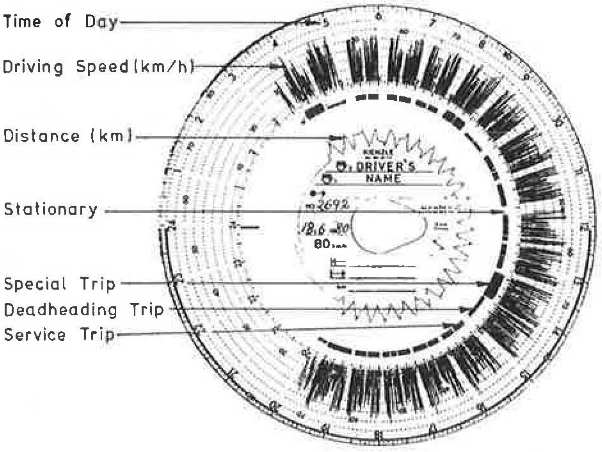
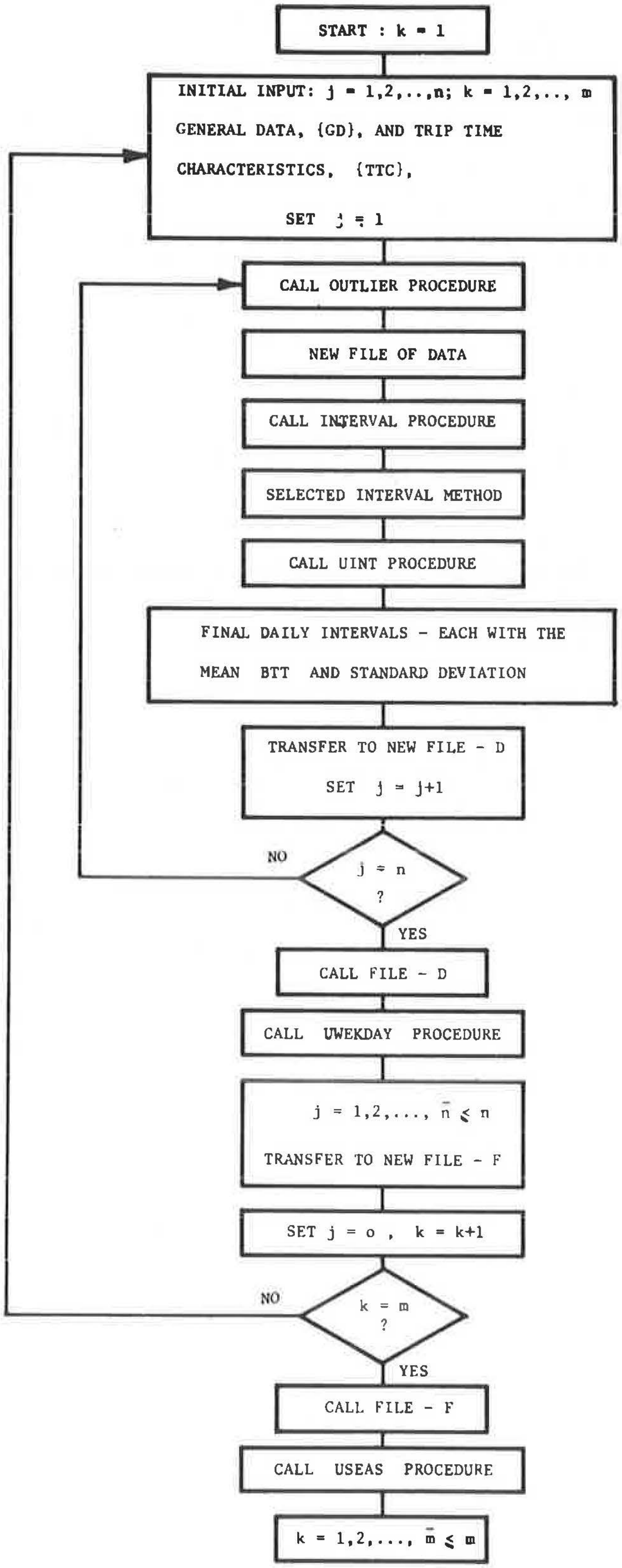


Figure 2. Flowchart of procedures for determining BTT values.



in less than 5 min). When the bus fleet supplies data in the range of 1000 or more diagram charts daily, an alternative is to process the data by using a computer. Data are inputted by means of an optical reader. The Kienzle Company has developed a computerized system (Kienzle FOS 1613) that can analyze data recorded on the diagram charts in seconds by means of an optical electronic process. Standard and supplementary data can be fed into the unit either manually, by means of a floppy disc unit, or by data communications.

The Kienzle computer program is not suited for analyzing and processing travel-time data and is intended for aggregate data for each needed interval (for a maximum of nine intervals per diagram chart for one optical reading), such as total waiting time in an interval and total travel time in an interval. An additional alternative is the separate use of the optical reader to transform into digital numbers the data on the diagram charts. These data are then manually transferred to magnetic tapes for computer analysis.

STATISTICAL METHODS FOR DATA PROCESSING OF BTT

The following section deals with the quantitative aspects of the analysis of travel-time data. It should be remembered that additional managerial data can be obtained from the tachograph diagram chart. However, this paper is focused only on travel time (BTT), which is a most vital factor in scheduling buses to trips.

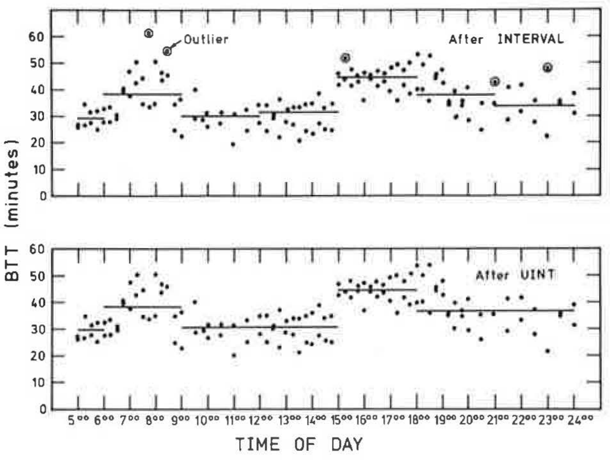
Outline of Methods

The main objective of data processing is to create a data base on bus travel times for different cross sections of the day, the week, and the season. In other words, one is interested in obtaining mean values and standard deviations for $BTT_{i,j,k}$, where i, j, and k are indexes for indicating daily, weekly, and seasonal divisions, respectively.

It is clear that the number of values of i,j,k will affect the size of the memory needed for storage of data in the computer. The values of $BTT_{i,j,k}$ will aid the planner in bus work schedules, both with the Gantt charts and with the interactive system between man and computer.

In discussing a bus system of the size of Egged (4000 lines), an approach based on the total values of $BTT_{i,j,k}$ for each line, or for a group of lines with similar characteristics, is needed. For this purpose, a systematic method for data processing was built on a wide-ranging sample basis. These data will be collected by use of the tachograph (or, alternatively, at the origin and destination points of each bus line, a method that will require large manpower resources).

Figure 3. Example of BTT data points for a bus line with means determined by the INTERVAL and UINT procedures.



From a statistical viewpoint, if there exists a large data bank that can be systematically updated, an analysis of variance can be carried out (based on the normality distribution assumption) in order to estimate the effects of i,j,k, the independent variables, on the dependent variable BTT. Afterwards, an analysis of the independent variables that were found to affect the dependent variable (at a desired level of significance) can be carried out by the use of contrasts. Finally, it is possible to apply multiple variable regression of the model.

In order to effectively carry out an analysis of variance on i,j,k, a data bank must be accumulated over a yearly period on the assumption that there were no physical changes along the bus route or in the location or quantity of bus stops. Since it is well known that bus lines are liable to physical changes in a dynamic way, it is questionable whether the data bank for BTT values can rely on a yearly base. More than this, it is desirable that the process that determines the relation of $BTT_{i,j,k}$ al-

Figure 4. Record of OUTLIER, INTERVAL, and UINT procedures for Figure 3 example.

```
NEXT SET FOR BUS            1   IN DAY  30   FROM   HAIFA          TO  HEDERA


             *OUTLIERS
1      7H   45M     62.00
1      8H   30M     55.00
1     15H   15M     51.00                TOTAL (INPUT) NUMBER OF BUSES: 126
1     21H    0M     44.00
1     23H    0M     49.00                NUMBER OF BUSES WITHOUT OUTLIERS: 121



                     F-TEST & T-TEST FOR GIVEN SET OF BUSES
                     ======================================


                   FIRST STEP - F-TEST TO ACCEPT THE METHOD FOR
                DIVISION OF INTERVALS DUE TO BTT (BUS TRAVEL TIME).

                         THE SIGNS FOR METHODS :
                         -----------------------

                         A-BY ONE HOUR
                         B-BY TWO HOURS
                         C-BY THREE HOURS
                         D-THE WHOLE DAY



  ---------------------------------------------------------------------
  | COMPARISION    | F-CALCULATED |    F-TABLE     |  CONCLUSION      |
  ---------------------------------------------------------------------
  |    A      D    |    1.9229    |     1.35*      |   CONTINUE       |
  |    A      C    |    1.1502    |     1.35       | C   ACCEPTED     |

THE ACCEPTED METHOD OF DIVISION TO INTERVALS IS   C

            NEXT STEP - T-TEST BETWEEN THE INTERVALS OF THIS METHOD



                       THE TOTAL RESULT AFTER T-TEST IS:
                       =================================


 --------------------------------------------------------------------------
|     INTEGER       |   ACTUAL        |   MEAN    |  ST.DEV.  |  NUMBER OF  |
|     INTERVAL      |   INTERVAL      |           |           |   BUSES     |
|---5:00<T<= 6:00---| 5: 0   6: 0 ----|-- 29.40 --|---3.5022--|- 10 --------|
|---6:00<T<= 9:00---| 6:15   9: 0 ----|-- 38.18 --|---8.0688--|- 22 --------|
|---9:00<T<=15:00---| 9:30  15: 0 ----|-- 30.86 --|---6.0802--|- 36 --------|
|--15:00<T<=18:00---|15:15  18: 0 ----|-- 44.74 --|---4.5447--|- 23 --------|
|--18:00<T<=24:00---|18:15  24: 0 ----|-- 36.93 --|---6.9829--|- 30 --------|
 --------------------------------------------------------------------------
```

low for intermediate involvement of those responsible for data collection. This involvement can be expressed by the identification of outliers whose cause is known and by practical decisions relating to changes in the statistical criteria (which are combined in the process) in relation to different bus lines.

As a result, it was decided to base the method for determining BTT values on a number of criteria for characterizing outliers--for division of the day into time used, for division of the week into homogeneous days, and for division of the year into seasons. If there are no physical changes for a given bus line over a yearly period, and a data bank for BTT values exists, there is a possibility of carrying out analysis of variance and contrasts for i,j,k. In addition, it should be remembered that the objective is not to build a statistical model for simulation or control but to build a value system for $BTT_{i,j,k}$, which can be of greater aid in realistic planning than a single mean value for all days of the year (such as that currently used by Egged).

The statistical method was chosen according to the following criteria: It must be simple, flexible, systematic, and practical. The method, shown in the flowchart in Figure 2, is made up of four main components:

1. Exclusion of outliers (OUTLIER procedure),
2. Division of day into intervals (INTERVAL procedure),
3. Union of intervals (UINT procedure), and
4. Union of days for weekly and seasonal cross sections (UWEKDAY-USEAS procedure).

The first three components relate to the data on a daily basis, and the fourth component serves as a tool for determining the division of j and k.

Figure 2 describes the course of the method. At the onset, data are assembled into two sets: (a) general data (GT), which include the number of buses in the set, bus-line number, origin, destination, the day (or days) of the week, and the season, and (b) specific data (TCC), which include bus departure time (exact hour and minute), bus travel time, and type of bus. The outliers are deleted from these data, and then a number of methods are tested for dividing the day into intervals (division for each hour, each 2 h, each 3 h, and one daily average). After the suitable method has been chosen (in relation to a statistical criterion), statistical tests are carried out to determine the possibility of unifying the intervals according to the chosen method. The procedure continues for the series of days j, and then the possibility of unifying the days (which are characterized by various indices of j) is examined. The next step examines the possibility of unifying a number of days from different seasons; this is possible if the division of days j in each season (or at least those chosen for unification) is similar. The procedure is described in detail in the complete report by Ceder (11).

Example of a Data Set

A PL/1 program has been written for all procedures shown in Figure 2. This program is in partial use in the following example, which considers a single day.

For a given bus line departing at a frequency of either every 15 or every 30 min, data were collected for two days (the same day for two weeks) at a total of 126 data points (see Figure 3). In the OUTLIER procedure, five outliers were found; these are marked in the upper portion of Figure 3 and also appear at the start of Figure 4, which is a computer record.

Following a run of the INTERVAL procedure, method C was chosen--that is, a division of the day into 3-h intervals, where the first hour is considered separately, as shown in the upper portion of Figure 3 and in Figure 4. The data then proceeded to the UINT procedure. Of the seven intervals in method C, two are united and only five intervals remain, as shown in the lower portion of Figure 3 and in Figure 4. This example does not include the UWEKDAY-USEAS procedure.

The last five intervals (each with a mean and standard deviation) are transferred to the planner for bus work schedules. This transfer can be made either automatically or manually. Determination of the BTT value for planning purposes will depend on the degree of certainty desired regarding the bus's arrival at its destination prior to or at the planned time. For this purpose, the mean is accompanied by a standard deviation value.

REFERENCES

1. A. Ceder and D. Gonen. The Operational Planning Process of a Bus Company. UITP Review, Vol. 29, No. 3, 1980, pp. 199-218.
2. A. Ceder and H.I. Stern. A Deficit Function Procedure with Deadheading Trip Insertions for Fleet Size Reduction. Transportation Science, Vol. 16, No. 1, 1981.
3. R.A. Chapman, H.E. Gault, and I.A. Jenkins. The Operation of Urban Bus Routes: Volume 1--Background and Preliminary Analysis. Traffic Engineering and Control, June 1977, pp. 294-298.
4. R.A. Chapman, H.E. Gault, and I.A. Jenkins. The Operation of Urban Bus Routes: Volume 2--Sources of Irregularity. Traffic Engineering and Control, July-Aug., 1977, pp. 364-367.
5. R.A. Chapman, H.E. Gault, and I.A. Jenkins. The Operation of Urban Bus Routes: Volume 3--Wider Aspects of Operation. Traffic Engineering and Control, Sept. 1977, pp. 416-419.
6. P.H. Bly and R.L. Jackson. Evaluation of Bus Control Strategies by Simulation. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. LR 637, 1974.
7. R.L. Jackson. Evaluation by Simulation of Control Strategies for a High Frequency Bus Service. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. LR 807, 1977.
8. P.A. Anderson, A. Hermansson, and E. Tengvald. Analysis and Simulation of an Urban Bus Route. Transportation Research, Vol. 13A, 1979, pp. 439-466.
9. M.A. Turnquist and L.A. Bowman. The Effects of Network Structure on Reliability of Transit Service. Transportation Research, Vol. 14B, 1980, pp. 79-86.
10. A. Ceder and S. Borovsky. The Tachograph as a Measuring Tool for the Planning Process of a Bus Company. Transport Department, Egged, Tel Aviv, Rept. 8-80, Jan. 1980.
11. A. Ceder. Practical Considerations and Methodology for Determining Dynamic Changes in Bus Travel Time. Technion--Israel Institute of Technology, Haifa, 1980.

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Development of an Automatic-Vehicle-Monitoring Simulation System

R.B. GOLDBLATT AND M. YEDLIN

The Automatic-Vehicle-Monitoring Simulation System (AVMSS) is described. AVMSS is an interactive bus-route simulation model designed to act as a test bed for the evaluation of automatic-vehicle-monitoring (AVM) strategies and tactics. The system is composed of three component programs: the Traffic Environment Generator (TEG), the Bus Schedule Generator (BSG), and the AVM Simulator (AVMS). The simulation system uses both macroscopic and microscopic simulation techniques. The macroscopic traffic-flow model used in the TEG program is based on the TRANSYT model. Buses are moved in the AVMS by using a microscopic time-scanning technique. The features of each component program are discussed, data requirements and the measures of effectiveness produced are presented, and AVM strategies embedded in the model are described.

Over the past 10 years, increasing concern with energy consumption, traffic congestion, and the environmental aspects of urban transportation systems has motivated the development of a wide range of techniques for improving urban bus operations. One method of improving service reliability is to give transit operators the capability of centralized and coordinated control of bus schedules and headways.

This paper presents the design of a software system to perform bus-route simulation. The system, the Automatic-Vehicle-Monitoring Simulation System (AVMSS), was designed as an engineering tool to aid in the development and evaluation of automatic-vehicle-monitoring (AVM) control tactics. These tactics would seek to improve the service reliability of bus systems.

BACKGROUND

The simulation of a bus transit system, with or without AVM control, is a description of dynamic processes operating within, and responding to, a dynamic environment. In this application, the dynamic processes pertain to the activities of each bus in the system. These activities include (a) accelerating, decelerating, and moving at free-flow speed; (b) responding to AVM control tactics; (c) responding to traffic control devices; and (d) servicing passengers at bus stations. Each of these activities is conditional on the following external factors, which, in aggregate, constitute the operating environment: (a) geometric constraints of the physical street system, (b) general traffic flow and signal conditions, (c) location and number of bus stations, (d) passenger demand and boarding and alighting, and (e) bus capacity, schedules, and transit rules.

Many of these factors vary with time. Since the intrinsic, potential instability of bus systems reflects both long- and short-term variability of the operating environment, it is essential that both components of variability be properly represented in any simulation program.

Three different classes of simulation models have been developed that meet these conditions: microscopic, macroscopic, and hybrid. A brief comparison of these classes of models is given below:

Class	Characteristics	Example
Microscopic	Explicit modeling of automobiles and buses, time scanning, complex code, costly to run, much detailed output	NETSIM (1)
Macroscopic	No discrete modeling of automobiles, modeling of bus travel time, event scanning, efficient computer memory, less detailed output	TRANSYT (2), TORG (3)
Hybrid	Macro treatment of automobiles, micro treatment of buses, event and time scanning	SUB (4), AVMSS (5)

Microscopic models tend to represent vehicles individually and their movements explicitly in great detail. Thus, they provide a high level of accuracy along with the ability to provide extremely detailed output. Macroscopic models sacrifice modeling detail to provide faster machine times and reduced computer-memory requirements. Hybrid models combine the features of both microscopic and macroscopic modeling techniques. One component of traffic can be treated with great detail while another is represented at a lower level of detail.

The choice of model classification during the design of a simulation program is dictated by the constraints placed on model performance. AVMSS had to be able to handle bus traffic and passenger transactions explicitly. No constraint was placed on the treatment of automobile traffic. Finally, the program had to be interactive and fit into a 32 000-word region of core. Hence, AVMSS was designed as a hybrid model; i.e., it models automobile traffic macroscopically and bus movements microscopically.

General Structure of AVMSS

On the basis of a functional analysis, AVMSS was designed as a system of three independent programs:

1. The stage 1 program, the Traffic Environment Generator (TEG), is a traffic simulation program to create a data base that defines the "traffic environment" and to store this data base on magnetic tape.
2. The stage 2 program, the Bus Schedule Generator (BSG), is a preprocessor program to create a data base that contains the schedules of all buses on the subject line, all passenger demand rates at all stations, and the scheduled times of arrival of buses on other lines. The data base is stored on magnetic tape.
3. The stage 3 program, the AVM Simulator (AVMS), is a microscopic bus-operations simulation program that includes the ability to interact with the operator (simulating the role of the dispatcher) so as to implement on-line AVM tactics and to simulate the consequences (i.e., system response).

Traffic Environment Generator

TEG is a macroscopic traffic simulation program based on a model developed by KLD Associates, Inc., for the Federal Highway Administration (6), which, in turn, is an elaboration and refinement of the flow model embedded in the TRANSYT program (2). TEG models the traffic flow on a network represented by "nodes" (intersections) that are connected by unidirectional "links" (one-way roadways). The network to be modeled consists of that portion of the physical street system that contains all possible bus paths that are to be specified by BSG and simulated by AVMS.

TEG describes the general traffic conditions on the network in the form of lane-specific statistical SERVICE and QUEUE histograms. The SERVICE histogram represents the time history of available service provided by the control device at the downstream intersection at a macroscopic level of detail. The QUEUE histogram describes the time history of vehicle queueing at the stop line. These two sets of histograms provide all the necessary information at this macroscopic level of detail to estimate the impedances experienced by buses due to the presence of other traffic.

The output of TEG consists of a tape that contains the SERVICE and QUEUE histograms for all relevant lanes of each link in the bus analysis network. Each histogram is created for a period of time known as the "time interval" (approximately 50-200 s). Other link-specific properties are also present on the tape.

Bus Schedule Generator

BSG was designed to process user-specified input to describe bus and bus-station operations. BSG reads and diagnostically checks the input data. Error messages are generated if problems are located. If no errors are detected, BSG creates a data file that will be used by the AVMS (stage 3).

AVM Simulator

AVMS is the heart of AVMSS. It is this program that moves buses through the network. Buses respond to traffic control and volume conditions specified by the TEG program. Buses also respond to schedules and passenger information as generated by BSG. AVMS gives the user interactive control over buses through the implementation of various AVM control strategies.

Bus Movement

Each bus moving through the AVM network is treated as a separate entity. As buses move through the network, they respond to certain external stimuli, including (a) surrounding traffic conditions, (b) traffic signal control states, (c) bus-driver characteristics, (d) bus-station characteristics, and (e) passenger loading and unloading characteristics.

Buses in motion accelerate in accordance with bus performance criteria until either a free-flow speed is achieved or the bus must begin to decelerate. A bus will decelerate in order to join a queue, enter a bus station, enter a layover point, or fall in behind another bus if there is no room to pass. When a bus falls in behind another bus, that bus moves in accordance with car-following logic.

Passenger Traffic

New passengers arrive at bus stations in accordance with a Poisson distribution about a mean arrival rate for the specific station. The algorithm used is adequate for routes where buses arrive at headways of less than 10 min.

Passenger boarding and alighting transactions are modeled by using calibration data obtained in the field. One important factor in passenger boarding and alighting transactions is bus type. A standard bus has a single rear door to allow alighting. An articulated bus has two rear doors. Passengers are assigned to either one or two rear doors depending on bus type.

AVM Tactics

A total of nine AVM control strategies have been implemented. These strategies fall into two major categories: (a) universal strategies, which apply to all buses in the network, require no operator intervention, and are automatically implemented when threshold values are reached, and (b) strategies that require operator interface during the course of a run (these strategies operate on specified bus runs only). Each of the nine AVM control strategies implemented is described briefly below.

1. Strategy 1, coordinated skip stop--Strategy 1 is initiated interactively by the operator when two buses are running close together. Bus A stops to pick up passengers at stations 1, 3, 5, 7, etc. Bus B stops to pick up passengers at stations 2, 4, 6, 8, etc. Buses A and B are allowed to leapfrog each other.
2. Strategy 2, discharge only--In strategy 2, passengers are allowed to get off at scheduled stops, and no passengers are allowed to board the bus. The bus will skip a stop if no one wishes to disembark.
3. Strategy 3, holding back a bus--Strategy 3 is a universal strategy that is not subject to operator intervention. Whenever a bus arrives at a stop earlier than a given schedule threshold, it waits.
4. Strategy 4, controlling trip start time--Strategy 4 allows a bus to leave a layover point or a terminal at a different time than its original schedule dictates. The schedule at each bus stop is modified accordingly.
5. Strategy 5, turning short--Strategy 5, an interactive strategy, allows the user to alter the route of a bus as it moves through the network. The bus proceeds to its next scheduled stop, where it discharges all its passengers. When all passengers have been removed from the bus, the bus then disappears from the network until it is scheduled to reappear somewhere else. When the bus reappears, it proceeds on the remainder of its route in a normal manner.
6. Strategy 6, gap filling--Interactive strategy 6 allows the operator to insert a new, unscheduled bus midroute in order to fill a long gap between buses. The user specifies the route, the insertion point, and the insertion time, and a new bus is generated and placed on the network.
7. Strategy 7, nonstop--A bus operating under interactive strategy 7 stops at the next scheduled stop, where any passengers who wish to get off do so. When the bus exits this station, it proceeds nonstop until the end point of the strategy is reached, at which time the bus begins to stop normally and will proceed along its schedule route.
8. Strategy 8, adjust schedule--The purpose of strategy 8 is to modify the scheduled time of arrival of a bus at its intermediate destinations along the route.
9. Strategy 9, in-vehicle display--Strategy 9, a universal strategy, is used to simulate the schedule performance meter developed for the AVM system.

This strategy applies to all buses on the network. When any bus exceeds one or more of the schedule deviation thresholds, driver aggressiveness is modified. As a bus becomes later and later, the driver becomes increasingly aggressive. Alternatively, a bus that is early will force the driver to become more lethargic.

Interactive Capabilities

The AVMS program is an interactive simulation model. Thus, the user has the ability to perform certain command and control functions. Among these are (a) creating a checkpoint, (b) generating system snapshots, (c) initiating or canceling AVM strategies, (d) ending interactive communication, and (e) terminating a run.

Input Requirements

Input for the TEG program has two functions:

1. The physical geometry of the traffic network must be described.
2. Information about traffic operations on the network is required.

The physical geometry of the network is described in terms of links and nodes. The information required includes link lengths, number of lanes, grade, lane channelization, and the number of adjoining nodes. Traffic operations are a combination of traffic-volume information and complete descriptions of the traffic control signal at the downstream end of a link.

Input for BSG is used to describe bus operations on the network being simulated. The paths buses must follow are input as a sequence of node numbers, bus-station numbers, and layover points, beginning at a terminal and ending at a terminal. Bus stations are described by their position and capacity, passenger arrival rates, and the proportion of the bus load alighting at that station. Bus schedules are input as the scheduled time of arrival at each bus station and the scheduled time of departure of a bus from a terminal or a layover point.

Input to AVMS is used to define threshold values for certain types of output and information on the universal AVM strategies to be implemented, if any. In addition, the user may input time-period adjustment factors that are used to vary traffic-flow information in order to model peaking characteristics.

Output

Each of the programs that make up the AVMSS has its own set of output. TEG and BSG output information concerning their respective functions so that the user has a complete description of the network, traffic flow, and bus operations.

The primary output describing system performance is produced by AVMS. This output falls into three categories: exception messages, system snapshots, and cumulative statistical reports.

Exception Messages

Whenever certain bus or bus-station measures of effectiveness exceed threshold values, one of the following exception messages is generated:

1. Late arrival--A bus arrives at a station at least X min late,
2. Early arrival--A bus arrives at a station at least Y min early,
3. Upper load factor--A bus leaves a station with at least X percent of passenger capacity filled,
4. Lower load factor--A bus leaves a station with less than Y percent of passenger capacity filled,
5. Upper headway--A bus arrives at a station more than X min later than the previous bus arrived at the same station,
6. Lower headway--A bus arrives at a station more than Y min later than the previous bus arrived at the same station, and
7. Passenger queue--A bus station has more than X passengers waiting to be served.

System Snapshots

System snapshots are interactively triggered reports that give a picture of the status of system elements at a given point in time. The following measures of effectiveness are output by system snapshots:

1. Bus status--run number, driver type, bus type, current link number, position (feet), status code, station-layover number, acceleration, speed, passenger load, destination, schedule deviation of last station, actual headway, nominal headway, load-factor variation, last station number, passengers on at last station, passengers off at last station, schedule deviation imposed by AVM command, and AVM strategies in force;
2. Station status--number of passengers waiting for a bus, number of buses in dwell, and number of buses on queue waiting to enter station; and
3. Link status--number of buses on the link, current queue length at the downstream node, and current service rate at the downstream node.

Cumulative Statistical Reports

Cumulative statistical reports are produced at the completion of a run. They include bus-run statistics and bus-station summaries. Schedule and headway performance reports are also produced. The type of data produced is outlined below:

1. Bus run completion summary, including run number, bus type, driver type, run time, schedule deviation, number of stops, travel time (person minutes), vehicle miles, number of passengers boarding, average passenger waiting time, root-mean-square excess load, and mean passenger trip delay;
2. Bus run schedule performance summary;
3. Bus run headway performance summary;
4. Bus run passenger performance summary;
5. Bus station summary, including station number, section number, link number, aggregate time station has no passengers, aggregate time buses wait to enter full stations, number of overloaded buses leaving the station, number of buses serviced, average dwell time, average number of loadings, and average number of alightings;
6. Bus station schedule performance summary; and
7. Bus station passenger performance summary.

CONCLUSIONS

The set of simulation programs described in this paper represents a powerful tool for the study of techniques to improve urban bus operations. As such it has a number of potential applications:

1. It may be used as a test bed to develop new strategies and tactics in a laboratory environment where traffic flow and passenger conditions are reproducible to form the basis for clear comparisons.
2. It can be used as a training device to allow dispatchers to recognize and correct problems with

bus operations before system service deteriorates significantly.

It is hoped that the use of the model will lead to a fulfillment of its potentials.

REFERENCES

1. KLD Associates, Inc. Network Flow Simulation for Urban Traffic Control System: Phase II. U.S. Department of Transportation, 1973. NTIS: PB 230 760-4.
2. D.I. Robertson. TRANSYT Method for Area Control Program Manual. Road Research Laboratory, Crowthorne, Berkshire, England, 1969.
3. I.A. Jenkins. A Comparison of Several Techniques for Simulating Bus Routes. Transport Operations Research Group, Univ. of Newcastle upon Tyne, England, Working Paper 14, Jan. 1976.
4. G. Radelat. Simulation of Urban Bus Operations on Signalized Arterials. Federal Highway Administration, U.S. Department of Transportation, Rept. FHWA-RD-74-6, Dec. 1973.
5. Conceptual Design of an Automatic Vehicle Monitoring Simulation System. KLD Associates, Inc., Huntington Station, NY, Sept. 1978.
6. M. Yedlin and E.B. Lieberman. Development of a TRANSYT-Based Traffic Simulation Model. TRB, Transportation Research Record 772, 1980, pp. 6-9.

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Abridgment

Analytic and Simulation Studies of Factors That Influence Bus-Signal-Priority Strategies

M. YEDLIN AND E.B. LIEBERMAN

Research intended to identify conditions under which the greatest benefits to transit operations can be realized by implementing a bus-signal-priority strategy is described. Two techniques are presented for studying the problem. An analytic model was developed to compare the performance of bus systems operating with and without bus signal preemption. Studies were undertaken to examine the effects and interrelations of several factors in terms of bus operations. These factors include signal density, traffic volume, maximum signal-preemption length, passenger volume, bus headways, signal split and cycle length, station location, and exclusive right-of-way for buses. Insights from the study pertaining to each of these factors are described. In addition, the Federal Highway Administration's network flow simulation (NETSIM) model was modified to incorporate a bus-signal-preemption strategy. Simulation studies produced results that confirmed some of the insights provided by the analytical model and yielded additional insights.

The application of a bus-signal-priority strategy must be part of an overall systems approach to bus operations. Signal strategies do not operate in a vacuum but in a total environment that consists of all other factors that constitute a bus mass transit system.

Although studies have been conducted on bus signal control (1-3), it has not yet been determined which factors are most important to the success of a bus-signal-preemption strategy. The objective of this study was to identify those conditions under which the greatest benefits to transit operations can be realized by implementing a bus-signal-priority strategy.

Two techniques were used in studying this problem. An analytic model was developed to study the behavior of a bus system operating with and without bus signal preemption. Parametric studies were then undertaken with the analytic model to examine the influence of many factors on the operational performance of a bus system. Because of the extensive interrelations among the effects of various factors on bus system performance, graphical representations of the results were prepared. These were carefully examined to determine the significant consequences of the factor interrelations. The most significant combinations of factors affecting system performance could then be identified.

In addition, the network flow simulation (NETSIM) model of the Federal Highway Administration (FHWA) was modified to incorporate provisions for a conditional signal-preemption strategy. Simulation studies were undertaken both to confirm some of the insights obtained by applying the analytic model and to study the effects of additional factors that were outside the scope of the analytic model. Measures of effectiveness (MOEs) generated by the models were used to determine the impact of bus signal preemption under various conditions.

ANALYTIC STUDY

An analytic study (4) was conducted to quantify the sensitivity of various bus operating characteristics of a transit system (stops per mile, travel-time reduction, and percentage of travel-time reduction) to many of the factors that influence bus operations. These factors include signal density (intersections per mile), cycle split, bus headway, cycle length, traffic volume, bus passenger demand, maximum phase extension and truncation time, buses in exclusive right-of-way or in mixed traffic, preemption strategies of green extension only and green extension or red truncation, and station location [such as near side every block, far side every block, and near side every third block (express service)].

This study consisted of the following steps:

1. Developing analytic expressions that relate bus operating characteristics to these contributing factors,
2. Applying these expressions to specified bus environments,
3. Organizing the results in a manner that exhibits the underlying relations, and

4. Deriving conclusions by examining these results.

The set of analytic expressions constituted a macroscopic model of bus operations. Although such a model, by its nature, requires the application of simplifying assumptions, sufficient detail is retained to satisfactorily represent bus operations. Bus trajectories include acceleration and deceleration modes as well as the cruise mode. (On short links buses cannot achieve the cruise mode, and this behavior is properly represented.)

The interaction between adjoining approaches along an arterial is taken into account. Buses that are stopped at the upstream intersection of an approach, either by the signal or to service passengers at a station, experience different trajectories on the subject approach than buses that are not stopped on the upstream approach. The model also estimates the expected value of delay experienced by buses during dwell, in a queue, and as a result of a red signal phase.

As a result of parameter studies using this analytic model, the following insights can be drawn about each factor. Benefits reflect reduced transit travel time and stops. The detailed results of a study conducted over a wide range of all factors considered here are available elsewhere (4).

Vehicle Volume

The incremental benefits of bus signal preemption increase somewhat (less than 10 percent) as traffic volume increases.

Passenger Volume

Wide variations in passenger volume produce little variation in the level of bus-system-related benefits obtained by bus signal preemption, since signal preemption has no effect on dwell times.

Headways

The incremental benefits of bus signal preemption are only marginally influenced by bus frequency.

Preemption Strategy

The incremental benefits of a more aggressive signal-preemption strategy (green-phase extension or red-phase truncation) are more pronounced when buses mix with general traffic than when they have their own right-of-way. When a strategy of green extension of up to 30 s or red truncation is used for buses in mixed traffic, the level of service for buses approaches that attained by removing all signals. The more aggressive (and effective) the signal-preemption strategy, the greater the prospect of disruption to cross-street traffic (4).

Cycle Length

Bus travel time increases with signal cycle length for a given value of cycle split. The influence of signal cycle length on the benefits provided by bus signal preemption is very small.

Cycle Split

The incremental benefits of bus signal preemption on arterials where signals exhibit lower G/C ratios are greater than on arterials where the signals exhibit high G/C ratios (G = green time and C = cycle time).

Bus Right-of-Way

The incremental benefits of bus signal preemption are far greater when buses mix with general traffic than when they have an exclusive lane. When there is no exclusive bus lane, the incremental benefits of signal preemption are far greater when the bus system has near-side stations than when it has far-side stations. The provision of an exclusive lane for a bus system with far-side stations cannot be justified by an improvement in bus performance, either with or without bus signal preemption. Hence, an exclusive bus lane is more effective for systems with near-side bus stations.

Signal Density

The incremental benefits of signal preemption increase with signal density, regardless of all other factors.

Bus Stations

Bus signal preemption seems more effective for systems with near-side bus stations than for those with far-side stations; travel times for bus systems with far-side stations are about 10 percent less than those with near-side stations. The effectiveness of bus signal preemption is independent of station spacing.

In general, bus signal preemption offers improvements by reducing both travel time and the number of stops due to signal control. For example, bus signal preemption provides approximately a 1.8-min improvement in bus travel time over a distance of 1 mile for a signal density of 8 signals/mile, when the maximum extension-truncation is 15 s, stations are near side, buses mix with traffic, and traffic volume is moderate.

SIMULATION STUDIES

In order to confirm and supplement the results of the macroscopic analytic studies, several experiments were performed by applying the microscopically detailed NETSIM model. For this application, traffic operations on both the main-street and cross-street approaches were considered.

The NETSIM program was modified to incorporate a responsive bus-signal-preemption strategy. This algorithm scans all approaches to each intersection of the analysis network to determine whether buses are "within range" of the signal control so that decisions can be made concerning signal timing. This preemption strategy permits either an extension of the current phase or a truncation of the current signal phase, depending on conditions. These decisions are constrained by limitations on minimum phase duration and maximum green extension so as to replicate a realistic strategy. In addition, truncation of a phase is not permitted if the prior phase was extended and vice versa.

Three different network configurations were executed by using the modified NETSIM model:

1. Case 1--An isolated intersection where buses traverse both directions along the main street and there are no buses on the cross streets,
2. Case 2--An isolated intersection where bus traffic exists on all approaches (unlike case 1, the buses compete for the signal preemption), and
3. Case 3--An arterial section, consisting of seven streets and intersections, along which bus traffic is routed while the cross streets contain only general traffic and no bus activity.

The signal control timing was designed in each case by assigning cycle lengths and splits according to Webster's criteria (5).

Table 1. NETSIM case studies.

Case	Volume[a] (vehicles/h/lane)	Bus Headway		Preemption Condition	Bus Delay	Total Person Delay
		Main Street	Cross Street			
1	250	5 min, 3 min	—	No preemption (min)	12	1 311
				Preemption (min)	4	974
				Change (%)	-67	-26
2	250	5 min, 3 min	5 min, 3 min	No preemption (min)		
				Main Street	47	3 929
				Cross Street	30	
				Preemption (min)		
				Main Street	41	3 377
				Cross Street	24	
				Change (%)		
				Main Street	-13	-14
				Cross Street	-20	
	500	70 s, 40 s	80 s	No preemption (min)		
				Main Street	250	19 276
				Cross Street	138	
				Preemption (min)		
				Main Street	210	17 460
				Cross Street	138	
				Change (%)		
				Main Street	-16	-9
				Cross Street	—	
3	250	5 min, 3 min	—	No preemption (min)	70	7 976
				Preemption (min)	24	3 686
				Change (%)	-66	-54

[a] All directions.

Bus Signal Preemption at an Isolated Intersection

Main-Street Buses Only

Case 1 examined an isolated intersection with moderate traffic volumes of 250 vehicles/h/lane in all directions. Buses appeared on the main street only, at headways of 3 min in one direction and 5 min in the opposing direction. These conditions corresponded to a volume/capacity ratio of approximately 0.33 for each intersection approach.

By using the modified NETSIM model, it was found that a bus-signal-preemption strategy could significantly reduce bus delay and overall person delay while not significantly affecting other traffic operations. Assuming 1.3 persons/automobile and 40 persons/bus, Table 1 gives a reduction in person delay of 26 percent. In addition, buses along the main street actually experienced reductions in delay of 67 percent. Delay to all vehicles on all approaches showed a very slight (3 percent) improvement.

Buses on All Approaches

In case 2, in which cross-street buses competed with main-street buses for signal preemption, preemption caused no disruption of general traffic and no significant shift in service equity between main- and cross-street approaches while providing a moderate improvement in the performance of buses. As data given in Table 1 show, total person delay was reduced by bus signal preemption by approximately 14 percent when buses competed for service compared with the earlier value of 26 percent without such competition.

A variation of this case explored the performance of bus signal preemption under conditions of high traffic volumes, frequent bus arrivals, and buses competing for service at an intersection. Here, traffic volumes were increased to 500 vehicles/h/lane. Bus headways were 70 and 40 s on main-street approaches and 80 s on cross-street approaches.

The implementation of bus signal preemption under these conditions provided no benefits for the buses on the cross streets and a 16 percent reduction in bus delay on the main street. The net benefits expressed in terms of total person delay were less than 10 percent.

Bus Signal Preemption Along an Arterial

Case 3 considers arterial travel marked by moderate volumes of 250 vehicles/h/lane and bus headways of 3 and 5 min, respectively, in the two directions. Here, as Table 1 indicates, the bus-signal-preemption strategy reduced bus delay by a highly significant 66 percent along the arterial. Person delay was reduced by 54 percent.

It is of interest to relate these results to those of the intersection in case 1. Although the two cases are not directly comparable (the cross-street volumes differ), it is seen that the benefits for a single intersection are substantially lower than those of the arterial: 26 versus 54 percent reduction in person delay. This implies that the installation of signal-preemption capability on a system of intersections may provide a compounding benefit. The reduction in bus travel time is approximately 1.5 min/mile, compared with the approximately 1.8 min/mile obtained with the more macroscopic analytic study for similar conditions.

CONCLUSIONS

Application of the NETSIM model to a limited number of cases produced results that confirmed those provided by the macroscopic analysis and provided some additional conclusions:

1. When bus arrivals on competing approaches are serviced by a signal-preemption policy, there is a net benefit to the buses. This benefit is significantly less than the benefits that would accrue if buses were not competing for service.
2. Bus signal preemption is most efficient when bus arrivals are less frequent than one per signal cycle, since there is a greater opportunity to respond to discrete arrivals. When bus volume is very heavy, strong consideration should be given to providing an exclusive right-of-way (lane) for that period of time.
3. Signal systems equipped with bus-signal-preemption capability may provide greater benefits than

would be provided by applying signal preemption to isolated intersections. There appears to be a "compounding" of benefits along arterials that are so controlled.

In summary, analytic and simulation modeling of transit operations controlled by a bus-signal-preemption policy indicates that under well-defined conditions significant benefits may accrue in terms of reduced travel time without disrupting general traffic. The particular conditions and factors that promote these incremental benefits have been identified.

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REFERENCES

1. Development of a Bus Signal Pre-Emption Policy and a System Analysis of Bus Operations. KLD Associates, Inc., Huntington Station, NY, KLD TR-11, April 1973.
2. J.A. Wattleworth and others. Evaluation of Bus-Priority Strategies on Northwest Seventh Avenue in Miami. TRB, Transportation Research Record 626, 1977, pp. 32-35.
3. L.E. Rechbell and B.A. Van Averbelle. Bus Priority at Traffic Control Signals. Traffic Engineering and Control, Vol. 14, No. 2, June 1972.
4. M. Yedlin and others. Bus Signal Priority Strategies: An Assessment of Future Research Needs. Federal Highway Administration, U.S. Department of Transportation, Rept FHWA-RD-80-043, June 1980.
5. F.V. Webster. Traffic Signal Settings. Her Majesty's Stationery Office, London, Road Research Tech. Paper 39, 1958.

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Transportation for the 1980 Winter Olympics: A Retrospective Look

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A review of transportation planning for the 1980 Winter Olympics in Lake Placid, New York, and the implementation of the plan is presented. The many events that led up to the Olympics, such as the purchase of land for parking lots, the planning of the bus system, and the reconstruction of highway facilities, are described briefly. The operation of the bus system during the Olympics is examined closely. Both newspaper accounts and first-hand knowledge are used to ensure an accurate representation of events. The roles of and relations between the New York State Department of Transportation and the Lake Placid Olympic Organizing Committee are examined.

When Lake Placid, New York, was selected as the site of the 1980 Winter Olympics, the world wondered if a small town could run them successfully. Several critical problems were immediately realized. One of the greatest areas of concern was the problem of moving an estimated 50 000 people within an area that usually had 3000 residents. Limited housing made this issue even tougher, since 20 000-30 000 people would have to arrive and leave every day.

The Lake Placid Olympic Organizing Committee (LPOOC), a private corporation made up mostly of local Lake Placid citizens, turned to the New York State Department of Transportation (NYSDOT) for answers to the transportation questions. NYSDOT was asked to design a feasible plan to transport visitors. The plan, after review by LPOOC, was to be implemented by the organizing committee. The Olympic Transportation Plan (1) met the various environmental constraints, minimized the impact to local residents and spectators, and yet allowed tens of thousands of people to witness the 1980 Winter Olympics.

The plan's five basic elements were (a) restriction of automobile access into the area, (b) parking in peripheral parking lots for spectators arriving by automobile, (c) provision of transportation in the Olympic area by means of a shuttle-bus system, (d) enforcement of speed traffic controls, and (e) sale of 50 percent of all event tickets available to the public only as part of a charter bus, train, or air package.

NYSDOT and transportation consultants hired by LPOOC thoroughly tested and reviewed the plan by means of a series of computer programs. Assuming that all of the above basic elements would be conscientiously implemented, these professionals were confident that, except for possibly a few peak hours at the largest events, delays would be minimal and travel in the area possible.

PLANNING THROUGH 1976

The LPOOC planning efforts were endorsed by a local referendum in 1973, by a joint resolution of the New York State Legislature in 1974, by a concurrent resolution of the U.S. Congress in 1975, and by actions of Presidents Nixon, Ford, and Carter and New York State Governors Wilson and Carey. LPOOC requested NYSDOT to examine existing facilities and determine what actions were required. One of the state's first steps was to inventory the transportation facilities as well as other areas that would affect transportation (2). A series of program information reports (PIRs) was issued. These reports included inventories of highways, lodgings, and restaurants.

Highway access to the Lake Placid area consisted of three 2-lane rural facilities, a winding and mountainous route with roads that approach from the south, west, and north. Two rail facilities serve the general area but would prove to have minimal impact. The closest airport capable of serving large planes and providing reasonably frequent service was 65 miles from Lake Placid in Clinton County. Closer airports could serve only general aviation or had limited ground storage for planes.

Existing bus service included daily intercity service along each of the highways (usually three to four buses per day). There is no local public bus transportation in this area.

The system had to be able to work even if the weather was poor. In 1979, for example, in the second week in February temperatures were as low as -30°F at night and the daytime temperature never got above zero. Furthermore, 24-in snowfalls are not uncommon in the area.

Preliminary analysis confirmed suspicions that unrestricted travel into the area would result in massive traffic tie-ups. There was simply not enough capacity to accommodate an unrestricted influx of spectators. The transportation system into the area, and within it, would impose limitations that must affect every aspect of the Olympic planning process. Related functions such as ticket sales, housing, and scheduling had to be flexible enough to meet the constraints imposed by the transportation system.

Beyond meeting the LPOOC's 1975 request for technical assistance, there was a strong commitment by the state that any planning effort must maximize public safety. This concern culminated in the passing of a law mandating that any transportation and security plan allow for public and government review.

An Environmental Impact Statement (EIS) provided an environmental framework that included the following constraints:

1. Be sensitive to the environment--The area is in the largest state-controlled wilderness and park area in the nation and is regulated by the Adirondack Park Agency, which oversees any development in the area.
2. Plan no major highway construction--This was in keeping with the desires of local officials and environmentally concerned agencies.
3. Use known technologies--The Olympics were too important to test untried techniques.
4. Look to post-Olympics use--The capital projects had to be in keeping with post-Olympics use.

A series of three reports (3-5) outlined the basic assumptions and developed a base plan around them. This transportation plan proposed a large internal bus circulation system and restricted automobile access into the area. Spectators were to park in a series of peripheral lots and be transported within the area during their visit by a shuttle-bus system. A preliminary estimate was made that 450 buses might be sufficient. The early analysis of the transportation system is summarized elsewhere (6). Although this system appeared workable, the strategy needed further testing and more refinement before the obviously expensive system was to be implemented by a financially constrained LPOOC.

PLANNING AND IMPLEMENTATION: 1977-1979

With the aid of a transportation consultant, NYSDOT developed a testing strategy that was as accurate as the existing data would allow but also flexible enough to adjust easily and accommodate changes in data or assumptions. The first step in this process was to use existing inventories, supplemented by field surveys, to identify all highway characteristics within the area and along entry routes. These data were used as input to computer simulation programs.

The event schedule was analyzed to select several peak hours of travel. Each peak hour was then broken down into its various components (officials, spectators, residents, etc.). By using available data on each group's travel patterns, the travel between internal locations was estimated, including the forecasting of origin-destination (O-D) pair volumes. The volumes were then assigned over the available routes. A computer program assisted in this effort by providing a description of the impact on each intersection from the accumulated needs.

These results were then analyzed on a system basis. Problem areas were identified and solutions were proposed. This process was repeated for several strategies until a workable solution for these peak hours was found. These peak hours were largely dependent on the event schedule, and a solution for one peak hour did not ensure that the same system would solve the problems found at another site for a different peak hour. To solve the problems, several peak hours were tested. Initial results of these efforts were summarized in the December 20, 1977, draft transportation plan (7). This report was then used as the basis for several informational meetings. Comments received from these meetings were incorporated into the plan.

This plan was submitted to LPOOC for review. LPOOC hired a transportation consultant to review NYSDOT efforts and coordinate implementation. Because there was concern that the cost of this transportation system (which called for 450 buses) would be prohibitive, the consultant was also directed to look for ways to reduce the costs (but maintain revenue).

The result of these efforts was the Olympic Transportation Plan of July 1979 (1). The basic elements of this plan were identical with those of the earlier plan, but it also included the following:

1. Snow and ice removal within the Olympic area that would attempt to reach bare pavement (thereby maximizing capacity);
2. Control of all private vehicles within the area to maximize highway capacity;
3. A 24-h transit system of 300 buses (peak hour) supported by a system of peripheral lots along each travel corridor for spectators arriving by automobile;
4. Pooling of official vehicles to minimize their impact while meeting the needs of athletes, officials, news media, and LPOOC family;
5. Assurance that 50 percent of all public ticket sales would require transportation to be included (this would minimize highway impact and reduce system cost); and
6. Enforcement of internal traffic regulations within the Olympic area to again maximize capacity (these included a one-way loop and restriction of parking at event sites to buses and official vehicles).

NYSDOT Role

Within this transportation plan, the state took responsibility for two general areas: highway-related and airport operations. During the Olympics, the state ran the Lake Placid heliport and Saranac's Lake Clear Airport (with the help of Pan-American Airlines).

In addition to snow and ice control, the highway responsibilities included

1. Signing--There was a need for thousands of

square feet of temporary signing leading to and into the Olympic area;

2. Highway reconstruction--Using an accelerated construction schedule, NYSDOT did general improvement work on several key inroads and internal highways;
3. Towing--The critical importance of keeping the highways open was also addressed through a towing contract that provided 24-h service along all critical highways;
4. Vehicle permit plan--The strategy to restrict access into the Olympic area was designed and implemented by NYSDOT and State Police forces; and
5. Coordination of existing intercity transportation services.

The state also provided expertise in transportation by offering LPOOC assistance in key activities that were falling behind schedule, monitoring LPOOC's progress in its areas of responsibility, and, when requested, assisting the consultants or LPOOC staff in related transportation issues.

The activities that fell behind schedule included the acquisition of the peripheral parking lots and the meeting of environmental regulations. NYSDOT testified in environmental hearings on Olympic and post-Olympic use of the peripheral lots. In addition, NYSDOT developed preliminary plans for each site and, when a negotiated agreement failed, New York State acquired the sites and leased them to LPOOC. NYSDOT also filed air quality permits and kept state and federal agencies informed of progress and decisions.

NYSDOT's mandate to monitor gave it the right to advise but not to control; its legislative mandate could not force LPOOC to react in a timely fashion, nor could there be a takeover of the contracts or operations of LPOOC (a private company) unless public safety was jeopardized. This could only occur during the actual operation. NYSDOT did have the right to report on problems to the Governor if the schedule of tasks was not progressing satisfactorily but, at least early in the process, reliance was placed on the assurances of experienced LPOOC officials that early difficulties were characteristic of large operations and that all problems would be resolved.

As an outside agency, NYSDOT was frequently not privy (nor should it have been) to contract negotiations. During the Olympics, the monitoring was expanded to include an entire NYSDOT task force whose members were located on-site wherever appropriate. The group was originally designed only to perform the NYSDOT highway and aviation responsibilities and to monitor LPOOC's transit responsibilities; it was this group of monitors, however, who early identified the problems, alerted the NYSDOT Commissioner, and, because it was necessary, actually began operating facilities. Because of their expertise, the NYSDOT monitors were able to assume a leadership function in several important areas.

LPOOC-Consultant Role

LPOOC took responsibility for the transportation requirements of the Olympics. Specifically, LPOOC tasks were to

1. Acquire, construct, operate, and restore the various parking facilities, including the peripheral parking lots, event sites, and centrally located bus facilities (for this task, LPOOC used a transportation consultant to finalize preliminary plans and a parking contractor to operate the facility, and construction was done by LPOOC's major contractor);
2. Operate the bus transportation system, which included contracting for 300 buses and managing their operation, including maintenance, dispatching, and control (LPOOC anticipated contracting out all but the management, which was to remain with LPOOC); and
3. Operate an official fleet of vehicles for LPOOC use.

The relative roles and duties of LPOOC and NYSDOT were defined in a series of correspondence. There were, however, some questions about the conditions under which NYSDOT could intercede. In New York State Senate hearings after the Olympics, this issue was discussed at length. It was concluded that the relationship had never been spelled out, although neither LPOOC nor state officials disagreed on individual responsibilities. (In fact, the issue was the timing of intervention, not who was in charge of any function.)

PLAN REFINEMENT

As the Olympics approached, LPOOC made various refinements in its portion of the plan. Most of these refinements were directed at reducing costs. When the state expressed the critical nature of the earlier assumption, LPOOC concurred and developed even more stringent assumptions. The main two changes to the original transportation plan concerned ticket and charter bus policy.

Not only would 50 percent of the tickets available to the public be packaged with public transportation (thereby reducing demand on peripheral parking lots), but also every effort would be made to package charter sales into bus loads of spectators with the same tickets. These charter buses would then become the sole transportation for these spectators, which would also reduce shuttle demand. Estimates for these sales were as high as half of the total charter sales.

Because these policy decisions were outside NYSDOT responsibility, it could only react with review critiques. NYSDOT questioned the feasibility of selling such ticket packages but, after receiving repeated assurances, hoped for the best. Fortunately, the original design capacities of the peripheral lots were not altered to consider this option because package sales were much less than LPOOC estimates. State efforts to monitor the ticket sales were exceedingly difficult. The ticket sales company experienced confusion and computer problems. However, NYSDOT received assurances through January that, although all sales were lagging, the ticket policy would be strictly adhered to and all would be well.

THE BUS CONTRACT

Even with the changes in charter ticket policy, there was still a margin of safety in most key areas that would provide safety valves if something should fail. However, the one element critical to all phases of the transportation plan was the bus contract.

Early in 1979, LPOOC began to actively look for a bus company to operate the shuttle system. School-bus operators were to be considered only for the village shuttle, since it was felt that mountainous access roads would reduce school-bus speeds to the point of reducing highway capacity. The search began during the end of the 1979 energy crisis. Contracts with major companies were not successful. Most companies were expecting a post-energy-crisis boom in demand and did not want to commit their fleets for such a short period. As the Olympics approached and ticket sales had not reached expectations, some transit companies did express interest in the contract in private discussions. However, by then, the LPOOC economic situation was becoming increasingly serious.

NYSDOT supplied LPOOC with a list of potential operators, suggested a consortium approach, and even drafted a request for proposal. LPOOC did its own searching and, when the operator was selected, LPOOC signed a contract it had developed. The new bus contractor was a Canadian firm, Autocar Rive Sud. Although LPOOC was looking for a company that could supply buses at $500-$550/bus/day, it negotiated with Rive Sud on the basis of $325/bus/day. Between the fiscal problems and the apparent difficulty of obtaining American buses, LPOOC felt there was no alternative but to contract with the Canadian firm.

Because NYSDOT had no involvement in the contract negotiations, it did not find out about these developments until November. NYSDOT immediately met with Rive Sud representatives in Montreal. Under law, NYSDOT had to begin inspecting buses and was anxious to begin working with the operator.

The contracts were not encouraging. Whereas the contract called for 300-350 full-sized intercity coaches (or as many as possible), Rive Sud actually owned 6. The Rive Sud repair facilities in Montreal were rented. It appears that they hoped to use their extensive fleet of school buses to serve the contract needs. NYSDOT bus inspectors were given a chance to review some of their fleet. Unfortunately, the school buses did not meet American safety standards in several key areas.

When informed of this problem, the president of the company declared, "There's still no problem. I will raise the fleet through subcontracts." In fact, for a significant part of the fleet, he did just that! He was able to subcontract over half of his fleet with a single American company, Bluebird Coach Line, Inc., which had buses that were state inspected.

OTHER CONCERNS

During the last half of 1979, other problems were surfacing. LPOOC suggested "busmeisters" (volunteers) to board each charter bus and act as tour guides. For lack of housing and funding, this never happened.

Additional demands were being placed on the dedicated spectator bus fleet. Buses from the 300 originally contracted for spectators only were being planned for the use of athletes and officials. The 75 originally planned for this purpose grew to more than 100, their use to be determined on a priority basis. Ticket sales were lagging, and no one seemed able to provide periodic sales reports. Construction of peripheral parking lots lagged. In fact, it was fortunate that the winter was mild because construction did not begin until late October and in fact was never completed before operations began.

MOVEMENT TOWARD IMPLEMENTATION: NOVEMBER-FEBRUARY

By January 1980, many of the concerns about the transportation plan were being effectively addressed. The bus contract was signed on December 10. The base bus schedules, maps, and demands were identified. Bus routes were determined. The fuel facilities had been planned. A tour package was highlighted and issued to the press. A dry run was held for a small event and, though there were some problems, it was a learning experience. The peripheral lots were 90 percent complete. A parking-lot contractor was selected.

Despite these steps, however, several critical areas were still unresolved in late January. These included the following:

1. The bus contractor promised weekly to supply a list of his fleet for state inspectors, but this did not occur until January. By then, NYSDOT inspectors had to exert almost superhuman effort to complete their work. Their reports were disconcerting. The buses were old (the contract called for 1976 or newer vehicles wherever possible), and some were rejected.
2. The trailers at the parking sites and the related operational facilities were not finalized. Some trailers needed heat, telephones, or power. Although pedestrian controls had been agreed to, none were in place. In particular, there were no devices designed to facilitate the loading of the buses.
3. No bus signing was in place, and there seemed to be no plans for driver training other than on the first day.
4. Although there was a parking-lot operator to collect money and park cars, there were no assigned personnel for bus operations or ground control.
5. The management team promised by LPOOC was woefully understaffed and overworked. The dispatchers were responsible to their own company only and were generally unavailable before the Olympics.
6. There were serious problems with ticket sales. NYSDOT received rumors that charter tickets were being sold individually and charter sales in general were low.
7. NYSDOT began hearing about labor problems with the bus contract. American unions, which were experiencing high local unemployment, were demanding a portion of the bus driver jobs. (We did not know this at the time, but this problem was the main reason Rive Sud used for supplying old buses; they did not want "school bus drivers" in their expensive intercity coaches.) NYSDOT was assured by LPOOC that the problem would be resolved.
8. Immigration papers had not been filed by LPOOC. After several warnings, the Canadian bus company management was asked to return to Canada until the matter was resolved.

As the deadline approached, many items remained undone. Individually none were insurmountable, but collectively they implied major problems. Despite repeated assurances, NYSDOT began receiving "off-the-record" reports from LPOOC staff that all was not well. In hindsight, even if NYSDOT had taken over at this point, it might have fared little better since many problems (e.g., ticket sales) had no answer at the time. There were still, however, valid reasons for hope. People experienced in large-scale events repeatedly assured NYSDOT that the problems and confusion encountered were typical.

The buses were finally inspected in late January. A new bus expert was named in January to head the management team. The buses scheduled for pre-Olympic duties were on time.

IMPLEMENTATION

As NYSDOT and LPOOC actually began to implement the transportation plan, the early indications were encouraging. The airport, although operating below estimated capacity, was functioning well. After some early confusion, the one-way system began working. The towing contract kept the roads clear. The public followed the stringent parking restrictions with few complaints. The event sites were operating training sessions with only minor problems.

Monday, February 11, was the first day of the shuttle-bus operation. No events were scheduled, but a religious ceremony was scheduled for that night and a few thousand people were expected to attend. The previous three days had been incredibly hectic. The NYSDOT staff assigned to monitor transit and traffic operations had dropped training in order to assist the LPOOC staff with many last-minute chores. Together, the two staffs made a lot of progress: Warming tents were installed at some locations, the work-site trailers got heat, and most of the signs were in place at the parking areas. Still, there was apprehension. Charter sales were unknown, staffing for bus operations was unclear, pedestrian planning was overrated, and many smaller issues had been neglected. There was no LPOOC staff at the lots to control the loading of buses and no channelization for crowd control.

The early morning hours on Monday, February 11, were generally quiet, and efforts to complete various tasks continued. Monday was the first day of travel restrictions, and most people in the Olympic area were not authorized to travel by motor vehicle except on the bus system. Lengthy delays were reported by the press. The New York Times reported that early in the day passengers were waiting as long as an hour and a half for shuttle buses that were supposed to arrive every 15 min. The press director for LPOOC was quoted as saying that a special bus program for athletes was operating smoothly and that there were only a few short delays on the buses carrying the first spectators away from the peripheral parking lots. With relatively few spectators in the area on Monday, a major victim of whatever flaws there were in the system appeared to be the press. LPOOC's solution to this problem was to take 40 buses from the public system and dedicate them strictly to the press.

Reports from NYSDOT transit monitors gave a picture of limited confusion but certainly no crisis; this was probably due to the light demand since no events were scheduled. A driver for one of the cooperating bus companies, who arrived at the Olympic Press Center, loaded three passengers, and was dispatched to Wilmington, said, "What they forgot to tell me was how to get there."

When people began to arrive for the Monday evening religious service, additional delays were reported. However, with the assistance of LPOOC's radio-taxi fleet, most of the visitors arrived at the Olympic arena on time. The end of the event went less smoothly. As several thousand people poured out of the arena and into the municipal lot, there were few buses there to meet them. Incredibly, there were no bus company dispatchers. NYSDOT monitors telephoned reports from the lot to the LPOOC bus dispatch center, but the telephone was frequently busy and respondents were obviously harried. They explained that drivers had worked all day and that many had just arrived. Fortunately, the crowd was patient (and the arena was used to keep them warm), and the problem was gradually eliminated.

Part of the problem on Monday arose from labor disputes. Labor unions insisted that American, not Canadian, drivers be used on the buses (there had been a similar, although reversed, situation at the 1976 Montreal Olympics). LPOOC suggested that because of these problems it had a driver shortage and did not have the supervisory staff it expected from Canada.

The next morning, Tuesday, February 12, the events of the previous day were discussed. Approximately 200 additional buses had arrived late Monday, and about 40 Canadians were given work permits to drive the buses. The only events scheduled for Tuesday were hockey games in Lake Placid Village, the first of which was at 1:00 p.m. Morning telephone reports were similar to those of early Monday. Bus service was irregular and confusion remained along some routes, but generally complaints were few and NYSDOT requests for additional service were noted by the dispatch center. An LPOOC spokesman was quoted in the press as saying that traffic flow was "working very, very good."

The first charter buses began to arrive on Tuesday, and drivers were totally confused. NYSDOT monitors at the charter parking areas (and in other locations) reported that there were no LPOOC staff to direct the charters and shuttle service to these charter parking areas was infrequent. The charter bus companies had received instructions with their tickets, but LPOOC's planned "busmeisters" or even on-site staff at the parking areas were lacking. In addition, the roadway signing was apparently not sufficient.

Another related problem was the lack of LPOOC staff for bus loading operations. The NYSDOT transit monitors had expected LPOOC temporary staff (mostly college students), but few arrived and none were trained. From the first day, the NYSDOT monitors, in addition to their normal duties, began loading buses, queuing spectators, and generally operating the spectator bus system.

The only on-site bus dispatchers were seven at two locations, and even those dispatchers worked for a specific company and took orders from the LPOOC center only when it did not conflict with their company's needs. NYSDOT monitors assumed an unplanned role and became bus dispatchers. The bus drivers welcomed their assistance as they, too, looked for direction.

Throughout these early days, a pattern was emerging on overall operations. The bus contract had been subcontracted by Rive Sud primarily to four bus companies. Each of these companies was assigned a portion of the bus system. Generally, these were corridors. There was little coordination between these companies. In fact, the dispatcher for each company was located in a different location and in one case could not even be reached by telephone! Our visits to the bus dispatcher center indicated confusion and command-control problems. The LPOOC management staff was simply overwhelmed, and each company went its own way.

For some corridors or some periods of time, this arrangement worked. Bus service could be excellent in one area while at the same time, in another corridor, people were kept waiting. At the event sites, this problem was highlighted. Some companies would not serve the event site because it was outside their corridor. Instead, transfers at the central loading area were required for spectators who were unfortunate enough to unknowingly cross a corridor service boundary! This had never been intended in planning and was obviously unworkable. The event schedule demanded efficient handling of the 300 buses.

There were delays in service for the hockey arena, and people were being inconvenienced beyond what anyone had expected. Along the three corridors, some buses would stop and others would not. The demand at the peripheral lots often so exceeded bus service that buses always left fully loaded and could not stop for waiting passengers.

In spite of these problems, overall the system had worked to some extent, mainly because of special efforts by two of the bus subcontractors.

Wednesday, February 13, was to be the first real test of the LPOOC bus system. There would be a huge crowd for the opening ceremonies and later a luge event at Mt. Van Hoevenburg. Crowds for the opening ceremony were originally estimated at 18 000-20 000 based on ticket sales. However, LPOOC had issued staff IDs to 22 000 people! Many of these IDs allowed nonticketed access to outdoor events.

Early Wednesday there were some problems, but until 11:00 a.m. most demand was met. The unpublished training events were causing some problems, and the need for crowd control became more and more apparent.

By 11:30 a.m., telephone reports from monitors were becoming frantic. Charter buses arrived to drop off passengers faster than the shuttle service could pick them up. Crowds at the lots were growing quickly, and hundreds of people were waiting at each parking site. The press reported that in Lake Placid visitors were lined up 10 deep for two city blocks. "Private enterprise" moved in, and rides in cars and trucks were being offered to people at the lots for fees of $3 or more.

The situation in the northern corridor was serious. The State Police began commandeering buses in order to get people out of the cold. A New York state trooper reported that he had tried to flag down a nearly empty bus to transport spectators to the opening ceremonies but "the driver said that wasn't on his route and he drove away." Crowds were everywhere. They continued to build in size, and the bus service could not handle it.

Monitors noted an absence of dispatchers or attendants at the event sites. By 1:30 p.m., the transfer problem had grown out of control at the central location. The bus companies were also becoming concerned. Even the reluctant companies began aiding their fellow subcontractors. By the start of the opening ceremonies, most spectators had reached the event except for those in the northern corridor. Here, hundreds missed the event. LPOOC dispatched personnel to get names for refunds. The New York Times reported that state transportation officials monitoring the traffic flow attributed the system's problems to a shortage of bus dispatchers and a resulting lack of coordination. However, Norman Hess, LPOOC's transportation director, denied that the system was short of bus drivers or dispatchers: "This is a massive plan and it worked substantially today. It moved about 23 000 people and left only a few hundred stranded."

The ending of the opening ceremonies was near disaster. Despite NYSDOT's frequent calls to begin stacking buses, none were there. (Later, NYSDOT found out that about 25 buses were waiting and had been sent away because of their fumes. By the time they returned, the crowds had swarmed the roadways and loading areas.) The buses that arrived were blocked by the crowds. NYSDOT, LPOOC, and the State Police did what they could. Every available bus was called in and the radio-taxi fleet as well. Many spectators simply walked the mile into town rather than wait for the buses.

By evening, the requested additional improvements to staffing and operations at the sites had not been provided. The NYSDOT monitors had been working 18-h shifts since Monday, and still no relief was in sight. The only assistance came from State Police and Environmental Conservation officers.

The basic problems plaguing the bus operations from the start continued and grew with the crowds. Charter buses were confused. There were even reports of stranded charter passengers (which were resolved). Bus dispatching was left to each company. There were no LPOOC staff at the peripheral lots and event sites. There was a need for operational staff, effective management (with central authority), and more buses or drivers (the drivers were being shuttled in daily, 60 miles each way, and by the end of the day they were exhausted).

On Wednesday evening, a luge event was scheduled for Mt. Van Hoevenberg. After some delays, everyone arrived. NYSDOT staff reported that the LPOOC bus management staff was off duty. The bus operation was left to the company dispatchers. Most of the bus drivers were exhausted and out of driving hours (there is a legal limit). Despite calls for more buses, there were simply none available when the event ended. Because of the cold, the crowd grew understandably ugly.

Three and one-half hours later, the spectators had been moved. But not before ambulances were dispatched for frostbite and exposure cases and the State Police had to break into a building to get spectators out of the cold.

After midnight, key state and LPOOC officials held an emergency meeting. In the all-night session, the decision was made for the state to effectively take over bus operations. A task force was appointed and went to work to address the immediate needs. Around 2:00 a.m., Greyhound was contacted through NYSDOT Commissioner Hennessy. Greyhound agreed to supply additional buses and a bus management team.

At 6:00 a.m., NYSDOT began calling resident engineers throughout the state to tell them to pack their bags and head to Lake Placid to help out. By 9:00 a.m., additional NYSDOT staff began to arrive to act as lot managers, help with crowd control, and assist with dispatching and management. Environmental Conservation officers added their resources by assisting in bus loading operations, providing radio communications to the dispatch center, and providing supplies to complete lot needs.

The Greyhound management team and a convoy of some 30 buses arrived in midafternoon; the buses were immediately pressed into service, and the management team went to work. Most of the 7500 hockey spectators who poured out of the arena after seeing the United States beat Czechoslovakia found buses waiting for them. In the words of a spectator on Thursday, "Today has worked very well. Yesterday was horrible."

Needs were addressed in all of the following areas:

1. More buses--Greyhound and school buses were contracted to supplement the existing fleet;
2. Operational staff--Fifty college students were hired by LPOOC to work for NYSDOT monitors;
3. Communications--New telephone lines and both an emergency Environmental Conservation mobile radio system and a similar NYSDOT system were put into operation within 12 h;
4. Supplies--Manpower and equipment (including barriers, cones, loudspeakers, and other things needed to effectively operate the bus loading areas) were made available; and
5. Effective cooperation--The bus subcontractors were requested to work under the new management team and supply a dispatcher full time to the center (they welcomed the arrangement, since by that time they too were looking for coordinated direction and all were anxious to do a good job).

The next few days were very hectic and difficult, but things began to smooth out as the new resources were integrated into the system. Many jury-rigged solutions were quickly found. The gravity fueling system, which took 40 min to fuel a bus, was supplemented with an electric pump that reduced fueling time to 4 min. An Environmental Conservation fire truck was pressed into service to wash bus windows; NYSDOT arranged to have box lunches delivered to drivers so they did not have to stop driving. Most important, the Greyhound-NYSDOT management team began to achieve control over the bus operation, and it began to operate as one coordinated system. The corridor division was eliminated, and buses were redispatched where needed and were lined up ahead of time to anticipate heavy demand.

All hoped and expected that management changes, extra Greyhound buses, and some additional school buses would be sufficient to turn things around. There was marked improvement on Thursday and Friday, but problems persisted, especially late in the day as drivers ran out of hours or became too tired. The 300 or so buses called for in the plan had arrived but were not available for the 16-h--or longer--day necessary because there was, in most cases, only one driver for each bus. Extra drivers appeared to be the answer, but no local housing was available. There were some problems on Saturday because the weather was very cold and because a very large number of visitors had arrived for the three-day weekend (Monday was a holiday). The line for buses at Keene was reported in the press to be five abreast and about a half-mile long.

New York State law restricted drivers to a certain number of hours and required that buses owned by school districts could only be used to transport schoolchildren or the elderly. The legislature had given special authority to LPOOC to contract with the districts but, given the precarious financial condition of LPOOC, districts were reluctant to sign contracts. On Saturday, February 16, Governor Carey declared a limited state of emergency for transportation that allowed the state to waive driver-hour restrictions and contract directly with school districts.

In the next few days, the total number of buses increased to around 500. This total allowed peak demands (all day) to be met in spite of the driver shortage. By Sunday, major problems began to disappear. About 15 000 persons watched the women's downhill race Sunday morning, and after the event some had to wait from 90 min to 2 h for buses. By early afternoon, more than 14 000 of the 18 000 spectators at the ski jump were cleared within 1 h. The longest wait at parking lots was approximately 1 h. Sunday, however, was very cold, and State Police reported approximately 150 cases of hypothermia. The problem was that many spectators did not know how to dress properly for the cold. State Police even reported some wearing tennis shoes and sandals. State Police and NYSDOT staff reported that people were complaining that they had arrived at parking lots 2 h early because of the bus shortage and did not have anything to do when they arrived at the event site long before starting time.

Some minor problems continued; getting drivers' box lunches to the right place at the right time was a major challenge. Bus destination signs became a popular souvenir, selling for $7 apiece. Parking lots thawed. Potholes developed. Finally, after an unusually dry winter, there was a snowstorm. Despite this, we were able to get through the last two-thirds of the Winter Olympics with little inconvenience to the public. There were some delays but nothing very serious. One alpine event at Whiteface was cleared within 30 min. However, some major events drew as many as 26 000 spectators, which created huge logistics problems. "I would have to have had 600 buses parked at the gate waiting for them," said a dispatcher for Greyhound. "That would have taken a parking lot two miles long and two miles wide."

By Tuesday of the second week, press stories about the Olympics transportation system were generally favorable. The bus system was no longer news. The U.S. hockey team and Eric Heiden dominated the headlines.

As mentioned earlier, after the Lake Placid Olympics, a committee of the New York State Legislature investigated the games (8). The general manager of LPOOC, Peter Spurney, was criticized for waiting "until everything fell apart" before asking the state for help. The committee found that "state officials were repeatedly misled about the state of readiness of the transportation system for Olympics spectators" and that the "state government, when it belatedly acknowledged its awareness of such mismanagement and misrepresentation, performed diligently in improving the transportation system."

CONCLUSIONS AND RECOMMENDATIONS

In the aftermath of an incredibly hectic time, the survivors of the transportation management team met together to discuss what had been learned and what recommendations could be made. These were as follows:

1. Efficient bus loading operations are absolutely essential for an effective system. They must be managed by an experienced individual, who should have adequate staff and resources.
2. Bus management and dispatchers should be well trained in advance and agree to follow the direction of a central management. Every day these dispatchers should meet to plan for the next day.
3. Bus contractors should include spare drivers (generally 1.5 drivers/bus) to ensure uninterrupted operation.
4. Communications must be available to all key locations and, if possible, be supported by a mobile unit.
5. Advance training must be provided for all personnel.
6. Access to events for support staff should be limited to locations where their numbers would not unduly influence operations.
7. Event schedules should be closely examined. Training events and estimates should be included, and possible early ending of events should be identified.

For future special events, the following recommendations are made:

1. All operators of events should be licensed to demonstrate their ability (financially and physically) to operate the event.
2. An approved transportation plan should be submitted as part of this demonstration.

ACKNOWLEDGMENT

The 1980 Winter Olympics transportation effort required the expertise of many professionals from many fields. We want to thank all those involved in this effort. Although the first few days were plagued with troubles, the problems were resolved expeditiously and, for the remainder of the games, the plan was successfully implemented.

REFERENCES

1. 13th Olympic Winter Games, Lake Placid 1980 Transportation Control Plan. New York State Department of Transportation, Albany, July 1979.
2. C. Carlson and others. The Transportation Inventory. New York State Department of Transportation, Albany, Aug. 1975.
3. M. Vecchio and G. Cohen. Travel to the 1980 Winter Olympics: A Preliminary Analysis. New York State Department of Transportation, Albany, Preliminary Res. Rept. 96, Nov. 1975.
4. R. Knighton, G. Cohen, and R. Albertin. Travel Demand at the 1980 Winter Olympics: Estimation and Analysis. New York State Department of Transportation, Albany, Preliminary Res. Rept. 100, June 1976.

5. G. Cohen, R. Knighton, and R. Albertin. Transportation Planning for the 1980 Winter Olympics. New York State Department of Transportation, Albany, Preliminary Res. Rept. 109, Aug. 1976.
6. G. Cohen, R. Albertin, and R. Knighton. Transportation Planning for the 1980 Winter Olympics. TRB, Transportation Research Record 626, 1977, pp. 10-12.
7. 13th Olympic Games, Lake Placid 1980 Transportation Plan. New York State Department of Transportation, Albany, Dec. 1977.
8. A Report on the 1980 Winter Olympic Games at Lake Placid. New York State Senate Committee on Investigations, Taxation, and Government Operations, Albany, April 1980, p. 24.

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Abridgment

Service-Sensitive Indicators for Short-Term Bus-Route Planning

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Transit performance indicators are useful means of monitoring existing systems and planning for future systems. The development of one type of transit performance indicator, a service-sensitive indicator, is discussed. The purpose of the service-sensitive indicator is to succinctly summarize the effectiveness and fairness of short-term route changes. Included in the indicator are considerations of the important performance variables perceived by riders: in-vehicle time, transfer time, walking time, waiting time, requirements to wait, and requirements to transfer. The service-sensitive indicator is applied to a case study—the improvement of transit service to the Milwaukee County Institutions Grounds, where major public medical care facilities are located. Because questions of equity are of greatest importance, the indicator is separately calculated for each of the potential rider groups. It is shown that the indicator measures the impacts of route alignment and route extensions on relevant population groups and does so without the need for extensive travel survey data.

Recently, there has been an increasing emphasis on the need to provide high-quality yet efficient public transportation services to all segments of the population and throughout urban areas. This emphasis has led to provision of services to population segments such as the elderly, the disabled, women, minorities, and low-income individuals. In addition, efforts have been made to offer convenient service to locations that provide different types of facilities and services, such as jobs, health care, education, recreation, and shopping. Consequently, transit operators have been faced with both the task of monitoring how well their systems serve diverse segments and geographic areas and the responsibility for developing new routes and schedules to remedy perceived deficiencies.

Systemwide indicators of transit performance have been developed to provide operators with information on how effectively and efficiently they are serving their communities. Examples of systemwide indicators are revenue passengers per service area population, revenue passengers per vehicle hour, and percentage of population served (1). Indicators such as these permit the operator to determine whether the transit system is improving over time and whether its quality of service is comparable to that of transit systems in similar communities. However, systemwide indicators are not prescriptive. Many potential short-term route or schedule changes are not revealed by using these overall aggregate measures.

If indicators are to be truly useful for planning system improvements, they must be "service sensitive". That is, a route or schedule change that qualitatively improves service should be reflected as a significant quantitative change in the appropriate indicators. Service-sensitive indicators should determine whether proposed system modifications are suitable, are efficient from current riders' perspectives, and are adequately serving groups of potential riders. Furthermore, service-sensitive indicators should be simple to calculate by using data normally available to transit operators, and they should not require extensive statistical analysis or model calibration.

The purpose of this paper is to demonstrate that service-sensitive indicators can be useful for short-term transit route planning and scheduling. A quality-of-service indicator is developed and applied to a route-planning problem in which equity issues are of paramount importance. Specifically, the problem concerns providing better transit service to the Milwaukee County Institutions Grounds (MCIG), where all the important county medical facilities are located. The example is particularly interesting because transit access to the location from low-income areas of Milwaukee is poor.

SERVICE-SENSITIVE INDICATOR

If a service-sensitive indicator is desired, then it should be based on a concise definition of service quality as perceived by riders. Surveys of current and potential bus riders have led to a better understanding of the notion of service quality (2,3). Riders want to reach desired destinations; they want to do so quickly and reliably. They want to avoid walking, waiting, transferring, or standing while riding. They want protection from weather, but they attach little importance to physical luxury while traveling.

For questions of equity, systemwide indicators may be made more service sensitive by simply breaking them down by population segments or by geographic areas. Rather than the percentage of the total population served, it is helpful to know the percentage of elderly, handicapped, economically disadvantaged, etc., within the service area. The decision as to which segments should be identified will depend on the reason behind the modification of the system.

The service-sensitive indicator developed in this paper is specifically designed to determine whether people have adequate access by transit to a major trip generator. The indicator is constructed by counting numbers of potential riders who can conveniently reach the destination of interest by transit. Of course, not all potential riders use transit to reach this destination. We are concerned with how many people have the opportunity to use the transit service, independent of whether they actually choose to travel by transit, by another mode, or not at all.

The difficulty in creating this indicator lies in producing a suitable measure of "convenience". In this paper, convenience is defined by using a psychological scale of the time spent in bus transit travel (3). The psychological scale provides ratings of major elements of transit travel: riding time, waiting time, transfer time, walking time in fair and poor weather, requirement to transfer, requirement to wait, riding time while standing, and multiple transfers.

The psychological scale was created by a technique known as magnitude estimation (4,5). A series of questions asking for a comparison between two trip descriptions was administered to 84 Chicago residents. The first trip description had a previously assigned numerical value and was used in every question for a particular respondent. This trip description was individually selected to be an everyday trip for each respondent. Respondents were asked to rate the second trip description in each question as a fraction or multiple of the first, making sure that the worst of the two trip descriptions was rated higher. By this means, 115 trips by bus transit, automobile, and walking were rated. Trip descriptions were created to isolate the effect of a single aspect of a trip--its purpose, mode, environmental conditions, requirement to transfer, waiting time, etc. Then, through statistical analysis [described fully elsewhere (3)], the contribution of each aspect to a trip-description rating could be computed.

The resulting ratings were on an arbitrary numerical scale. In order to render the ratings more concrete, they were mapped onto a scale representing minutes of travel to work by automobile. For example, if both a 20-min bus-transit trip with a 10-min wait and a 55-min automobile trip had ratings of x, then the bus-transit trip is evaluated to be equivalent to 55 min of automobile travel. The actual value of the ratings, x, becomes unimportant. Thus, there are two types of minutes used in the following analysis: actual and equivalent. It is important to note that a bus-transit trip that has a rating equivalent to 55 min of automobile travel represents substantially less bus-transit travel time. In this example, the actual bus-transit trip takes 30 min. Measuring the convenience of bus-transit trips in equivalent minutes of automobile travel has three advantages:

1. It is directly based on how riders and potential riders evaluate bus-transit trips.
2. It provides a means of comparing bus-transit trips in a consistent set of units.
3. It provides an immediate comparison with the most important competitive mode, the automobile.

The relation between equivalent automobile time and actual bus-transit time is summarized below:

Trip Element	Bus Travel Time (min)	Equivalent Automobile Travel Time (min)
In-vehicle time	10	13.2
	20	24.5
	30	35.2
	40	45.5
Wait time	5	11.0
	10	21.1
Wait requirement	0	9.9
Transfer time	5	10.0
	10	20.0
Transfer requirement	0	28.0
Fair-weather walking time	5	6.6
	10	13.3

The distinctions made here between wait requirements and waiting time and between transfer requirements and transfer time are not typical for bus-transit planning. The ratings show a strong unwillingness on the part of respondents to either transfer or wait. Once these wait and transfer requirements have been established, additional excess time is rated at about twice automobile travel time. Waiting, transferring, and walking are all represented in the table as occurring under fair-weather conditions. Riders are also assumed to have seat availability.

The ratings from the Chicago residents did not vary according to socioeconomic or personal characteristics of the respondents (3), and the ratings are consistent with value-of-time studies conducted in a variety of cities. Residents of Milwaukee, a city very close to Chicago in location and socioeconomic makeup, would not be expected to produce significantly different ratings.

The quality-of-service indicator is constructed by using a two-step procedure: (a) setting an automobile travel-time standard and (b) counting the number of persons in the appropriate population segment who can travel to the designated destination within that travel-time standard. Separate indicators are calculated for each population segment of interest. It is likely that a single standard will emerge as best for a particular planning problem.

CASE STUDY

MCIG is the location of major, publicly provided health care facilities and extensive private health care facilities within Milwaukee County. Approximately 8000 employees and 8000 nonemployees visit MCIG on any given weekday. MCIG is inconveniently located 6 miles to the west of the Milwaukee central business district (CBD). MCIG is well served by highways, but it is inadequately served by transit. Only three bus routes are near MCIG, and two of these bus routes serve the same east-west corridor. At its closest point, the single north-south route is 0.4 mile from the heart of the MCIG medical facilities.

The inadequate transit service to MCIG makes access for inpatients and outpatients especially difficult. Unlike most medical facilities, which draw their patients from proximate areas, patients coming to MCIG are heavily concentrated in an area just west, northwest, and southwest of the Milwaukee CBD. About 50 percent of MCIG patients reside in the "target area" shown in Figure 1. MCIG patients tend to be low income, and they are heavily dependent on publicly provided health care services.

Figure 1. Current Milwaukee County bus-transit service areas as defined by 30-, 60-, and 90-equivalent-min standards.

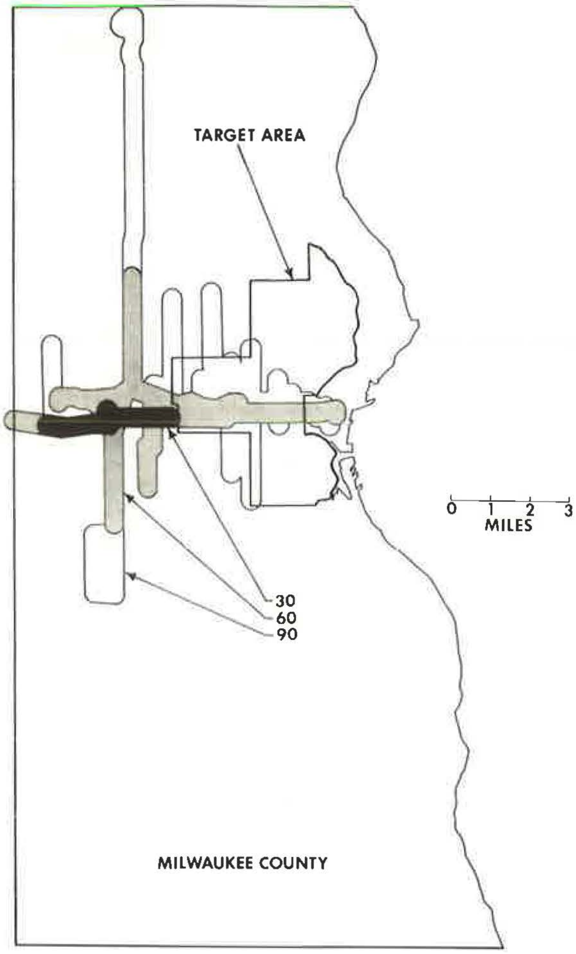

Table 1. Route alternatives for bus service to MCIG.

Alternative	Type	Description	Estimated Cost per Day ($)
A	Do nothing	Existing system	0
B	Alignment	Reroute 67, 71, and 10 into MCIG (current plan)	169
C	Extensions	Reroute 67, 71, and 10 into MCIG; extend 22 (on the north) to MCIG and open a loop within target area; branch 18 (on the south) to MCIG	1042
D	Extension-express	Reroute 67, 71, and 10 into MCIG; branch 18 (on the south) to MCIG; provide new north-south route in the northern target area with an express, freeway segment to MCIG	1127

Table 2. Percentage of population segment served by bus-transit alternatives under 90-equivalent-min standard.

Subgroup	Alternative A	B	C	D
Mental health patients	25.3	29.7	37.8	38.3
Hospital inpatients	26.0	29.7	41.0	41.7
Hospital outpatients	21.0	28.3	39.4	40.6
Medical students	42.7	53.9	57.5	55.8
Employees	23.0	29.6	34.2	32.5
General population	17.9	21.6	26.7	26.2

The objective of the case study was to determine whether short-term route changes would improve transit access for MCIG nonemployees. Service-sensitive indicators, as discussed in the previous section, were computed for various alternative route changes and for segments of nonemployees, employees, and the general population. Indicators were then compared to determine whether any of the alternatives were promising. The alternatives are summarized in Table 1.

In order to simplify calculation of the indicators, it was assumed that bus-transit riders would walk as far as 0.25 mile from their residences to a transit stop. This initial walk was not included in the measure of convenience. A walking speed of 3 ft/s was used to calculate final walking time between the bus route and the front door of the Milwaukee County General Hospital. Waiting time and transfer time were taken as half the headway of the appropriate route. Bus speeds on all streets and headways were for midday and were derived from timetables published by the Milwaukee County Transit System.

A 90-equivalent-min standard has been selected, primarily to yield an understanding of how well the target area is served. Figure 1 shows the existing service area as defined by 30-, 60-, and 90-equivalent-min standards. The target area is not served at all under the 30-min standard and is only minimally served under the 60-min standard. Western and central portions of the target area are served under the 90-min standard, although the total service area is still relatively small. The 90-min standard is used for the remaining indicator calculations.

The impacts of alternatives B, C, and D are summarized by the indicator values given in Table 2. The current plan of the Milwaukee County Transit System (alternative B) substantially increases the area within the 90-min standard at a small daily cost. For the various categories of patients and for employees, the increases in percentage served are between 3.2 and 7.3 percent; for medical students, the increase is 11.2 percent. Alternatives C and D, which call for new route segments, offer greater positive impact than alternative B but are much more costly. Alternatives C and D have almost identical impacts at identical costs. Table 2 indicates that these alternatives have the greatest impacts on patients; in relation to service to medical students and employees, they do not greatly improve on alternative B.

Although it is not the purpose of this paper to recommend particular alternatives, some conclusions as to the effectiveness of the plans can be drawn. The Milwaukee County Transit System plan (alternative B) appears meritorious because of its low cost. However, this plan only partly alleviates the problem of inadequate service to MCIG. The alternatives that include extensive route modifications (alternatives C and D) represent positive improvements but are also considerably more expensive than alternative B. Fortunately, bus-transit operators need not commit themselves to more than one route extension at a time. Alternative C would lend itself to piecemeal implementation, and an evaluation of generated revenues could be made after each new route extension had been introduced.

CONCLUSIONS

The advantages of service-sensitive indicators over other planning methods are emphasized by the MCIG case study. For example, travel demand models would have been useful in evaluating the alternatives, but it is unlikely that credible models could have been developed for population segments as unique as mental health patients.

The indicators were service sensitive without obviously exaggerating the magnitudes of impacts. The differences in routes between plans were small, but the indicators demonstrated which subgroups benefited most and revealed the relative magnitude of the benefits.

The measure of convenience, although adequate for the MCIG case study, is not complete. For route-planning problems where high load factors exist, the measure of convenience should be extended to include seat assurance (3). In communities where weather conditions are sufficiently poor to discourage walking, waiting, and transferring, the measure of convenience would require larger penalties associated with these trip elements (3). Once the definition of convenience has been established, required computations are straightforward and inexpensive.

Any additional service to one particular major trip generator will increase ridership to other locations as well. The indicator presented here is not directly applicable to estimating numbers of potential riders. However, methods have been developed for predicting ridership on the basis of population within walking distance of new bus routes (6), a measure similar to the indicator presented here. Further research into the relation between indicator values and ridership would be a beneficial step in improving current transit planning techniques.

REFERENCES

1. G.J. Fielding, R.E. Glauthier, and C.A. Lave. Performance Indicators for Transit Management. Transportation, Vol. 7, 1978, pp. 365-379.
2. M. Wachs. Consumer Attitudes Toward Transit Service: An Interpretative Review. Journal of the American Institute of Planners, Vol. 42, No. 1, Jan. 1976, pp. 96-104.
3. A.J. Horowitz. Subjective Value of Time in Bus Transit Travel. Transportation, Vol. 10, 1981 (in preparation).
4. S.S. Stevens. On the Operation Known as Judgement. American Scientist, Vol. 54, No. 4, 1966.
5. A.J. Horowitz. The Subjective Value of Time Spent in Travel. Transportation Research, Vol. 12, 1978, 385-393.
6. Peat, Marwick, Mitchell, and Company. Analyzing Transit Options for Small Urban Communities. U.S. Department of Transportation, Jan. 1978.

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Houston's I-45 Contraflow Transit Project

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A general report on the unique characteristics and results of Houston's North Freeway contraflow operation is presented, including the overwhelming response to the project by both bus and vanpool patrons. The North Freeway (I-45) Contraflow Transit Project began operation in August 1979 as Houston's first major effort to provide freeway preferential treatment for transit movement. The facility provides a daily travel-time saving of approximately 30 min during the line-haul portion of the commuting trip. Use of the lane is restricted to authorized vehicles, which include registered and approved buses and eight-passenger vanpools. The North Freeway project is the longest contraflow project in the country [15.4 km (9.6 miles)], the first to operate in both the morning and evening peak periods, and the first to restrict lane use to authorized vehicles that display an appropriate permit. In the first 44 weeks of operation, bus ridership increased by 227 percent and vanpool ridership increased by 114 percent. The project was initiated as an 18-month demonstration project sponsored in part by the Service and Methods Demonstration program of the Urban Mass Transportation Administration. The success of the project has led to a decision to continue operations beyond the demonstration period.

In 1974, shortly after the city of Houston purchased the local bus system from a private operator, discussions with the Texas State Department of Highways and Public Transportation (TSDHPT) were held regarding provisions of preferential treatment for transit. The North Freeway (I-45) was first recognized as appropriate for the application of a technique identified as "contraflow" in January 1975 (1). By March 1975, the Houston City Council authorized the Office of Public Transportation (OPT) to submit an application to the Urban Mass Transportation Administration (UMTA) requesting funds for initiation of preferential treatment on Houston freeways, specifically including contraflow on the North Freeway. In June 1975, UMTA approved a Service and Methods Demonstration (SMD) program Section 6 grant (under the Urban Mass Transportation Act of 1964, as amended) to implement corridor preferential treatments in Houston.

TSDHPT confirmed the feasibility of contraflow in March 1976 and by June 1977 had submitted final plans to the city along with approval from TSDHPT administration and the Federal Highway Administration (FHWA). In order to fully cover the costs of construction as they were defined, in November 1977 the city of Houston applied for and received an additional UMTA Section 5 grant (under the Act as cited above) (2). One week later, TSDHPT let bids for construction of contraflow. TSDHPT was also retained to supervise construction of the project. Construction began in February 1978 and was completed about 16 months later.

As part of the operations agreement reached with TSDHPT to supervise construction of the contraflow project, the city of Houston committed itself to operate the project and "prior to the commencement of such operation...the City's and State's authorized representatives shall promulgate and file an operating plan for the Project." No contraflow-lane (CFL) operation was to begin until this plan was approved and an ordinance duly enacted. The Metropolitan Transit Authority (MTA) assumed responsibility for this effort from the city upon the formation of MTA in 1979. The operating plan finalized and made legal the following: (a) operating hours and schedule, (b) requirements for authorized vehicles, (c) requirements for authorized drivers, (d) rules and regulations of the lane, (e) enforcement procedures, (f) CFL daily setup and take-down procedures, (g) CFL maintenance responsibility and procedures, and (h) emergency and breakdown procedures.

The plan was made the official ruling document by an MTA-TSDHPT operations agreement, which also provided a contraflow project management team to oversee the project and make amendments to the plan by mutual consent of the TSDHPT project engineer and the MTA project manager. This arrangement has proved to work very well. Amendments to the plan can be made quickly and effectively without amending the governing operations agreement.

Of special interest in securing the operations agreement was MTA's ability to enforce CFL restrictions. This was the first case in which TSDHPT imposed a restriction on the use of a traffic lane (versus restricting vehicle use of the general traffic lane). The Texas State Highway and Public Transportation Commission was empowered with this authority, but the city was required to enact an ordinance making this restriction legal and allowing for their police to enforce it. The ordinance was passed on July 25, 1979, and by August 15 MTA and the city of Houston enacted an agreement to provide enforcement for the project.

In concert with the contraflow project, TSDHPT initiated entry ramp controls with localized mainlane density detectors. This metering was similar to other installations on Houston freeways and was originally intended to provide improvements within freeway segments that are experiencing congestion in the peak direction. The approach was modified to incorporate anticipated impacts from CFL operation. It was hoped that minor amounts of off-peak direction metering would activate when needed at selective ramps, divert entering traffic along the frontage road or other parallel arterials, and alleviate level-of-service reductions on the through lanes.

Construction for ramp metering was jointly funded by the Federal-Aid Urban Systems (FAUS) program and TSDHPT. Work on this installation proceeded concurrently with contraflow construction, and the ramp controls were activated on March 20, 1979.

To make use of contraflow within a corridor that had little transit service, park-and-ride facilities were planned (3). The following descriptions provide a summary of these facilities:

1. North park-and-ride lot--Located at the northern terminus of the CFL, the north lot has the capacity to park 750 automobiles. This lot was built by TSDHPT, funded through the FAUS program, and opened in May 1980. The facility was filled to 85 percent of capacity after six months of operation.
2. Kuykendahl park-and-ride lot--Located approximately 10 km (6.5 miles) north of the northern terminus, the Kuykendahl facility was MTA's first constructed park-and-ride lot, opening in January 1980, and has the capacity to park 1300 automobiles. The facility was filled to 60 percent of capacity after nine months of operation.
3. Champions park-and-ride lot--The Champions lot was leased and began operating simultaneously when contraflow opened. Located approximately 22 km (14 miles) north of the northern terminus of the CFL, this lot has the capacity to park 300 automobiles and has been filled to capacity since the fourth month of operation.

CHARACTERISTICS OF NORTH FREEWAY

The North Freeway is a full standard six- and eight-lane Interstate facility completed between 1959 and 1962 that serves one of the fastest-growing corridors in Houston. The corridor is estimated to have experienced a 58 percent increase in population since 1970 and has a current population of more than 500 000 (4). According to TSDHPT automatic traffic counts, average weekday traffic on the North Freeway has increased from 96 000 vehicles in 1970 to a current 135 000. Travel-time surveys indicate that the distance that could be traveled during the peak hour in 1969 had been cut by 40 percent by 1976. The duration of reduced travel speeds [<32km/h (<20 miles/h)] had also increased to encompass 2-h peak periods each morning and afternoon. In view of a growth rate in traffic of almost 5 percent annually during the 1970s, the contraflow project was conceived as an immediate solution to the serious capacity problem that was developing and as a means to demonstrate public response to a premium transit service.

In 1974, when contraflow was being evaluated for the North Freeway, the peak-hour traffic splits were generally acceptable for this application. Acceptable standards for implementing contraflow included peak-direction distributions of 70 percent or more. I-45 in the morning had this attribute, but the trend of the afternoon peak was already beginning to be below this level. Ramp-metering improvements, already slated for installation on the freeway, were tailored to minimize contraflow impacts on free-flowing conditions in the off-peak direction. By the time contraflow became operational, the trend of the afternoon directional split was below 60 percent, and other measures described in this paper were taken to alleviate resultant traffic impacts.

There were a number of other freeway characteristics that allowed for or favored contraflow over other preferential freeway treatments. I-45 included full 3.6-m (12-ft) lanes, high-mast lighting, and, except at several bridge structures, continuous-median and other emergency parking shoulders. Parallel frontage roads throughout much of the project provided supplemental capacity from overflows that might be created in the off-peak direction when a lane was borrowed for CFL operation. In addition, wider-than-typical medians at the northern and southern extremities of the congested segment provided an opportunity to terminate contraflow, as described in the following section on project design.

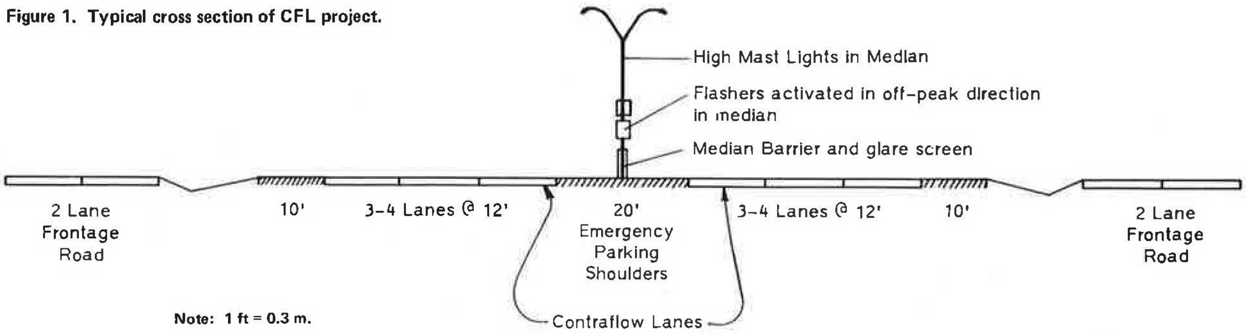
PROJECT DESIGN

The North Freeway CFL extends 15.4 km (9.6 miles) from the Houston downtown area. The CFL borrows one 3.6-m (12-ft) lane adjacent to the median in the off-peak direction for use during both peak periods. Continuous-median emergency shoulders are 3 m (10 ft) wide and allow for emergency passing of disabled vehicles throughout the majority of the lane. A typical cross section of the project is shown in Figure 1.

At the northern terminus, the freeway median widens to accommodate a left-hand entry ramp. This 30-m (100-ft) wide median separation between opposing directions facilitates a safe and effective CFL termination, as shown in Figure 2. Two entries enable authorized vehicles in the morning to enter the lane either from the peak direction or by a special buttonhook ramp from a primary arterial serving the nearby North Shepherd park-and-ride lot. In the afternoon, vehicles can similarly exit by either of two ramps at this location.

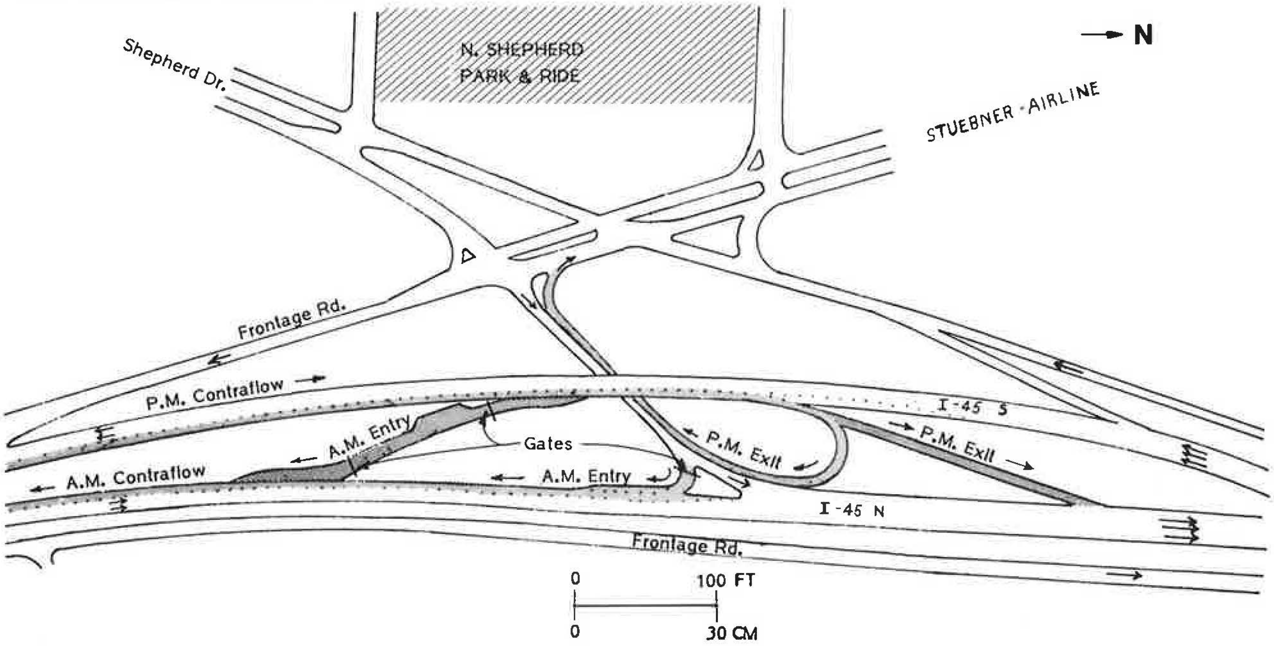
The southern terminus of contraflow is complicated with the interchange of I-10 with I-45. Prior to this interchange, a median crossover allows the morning contraflow operation to connect to a reversible-flow lane delineated on a 3-m inside shoulder of a viaduct portion of the southbound lanes of

Figure 1. Typical cross section of CFL project.



Note: 1 ft = 0.3 m.

Figure 2. North Shepherd terminus to CFL.



I-45, as shown in Figure 3. At the south end of the viaduct, a left-hand ramp is avoided by connecting the reversible shoulder lane to an exclusive reversible lane constructed within the median between ramps. This reversible lane feeds into an outbound ramp connector from downtown. During the morning period, this short connector also operates as a contraflow lane. This combination of lane treatments allows authorized vehicles to gain exclusive access to the downtown street network. The outbound CFL vehicles travel directly to the reversible-lane entry in mixed traffic.

At midpoint along the lane, a unique crossover has been constructed for intermediate entering and exiting capability and for emergency diversion of all CFL traffic in the event an incident blocks the lane further downstream. The crossover is designed with staggered openings for entering and exiting, as shown in Figure 4, and is separated from other traffic on either side by precast concrete median barriers.

Along the line-haul portion of the lane, contraflow warning devices include median signs and flashers every 300 m (1000 ft), diamond symbol markings on the pavement, changeable lane controls over the innermost two lanes at transition points, and use of 46-cm (18-in) pylons placed into predrilled holes in the pavement at intervals of every 12 m (40 ft).

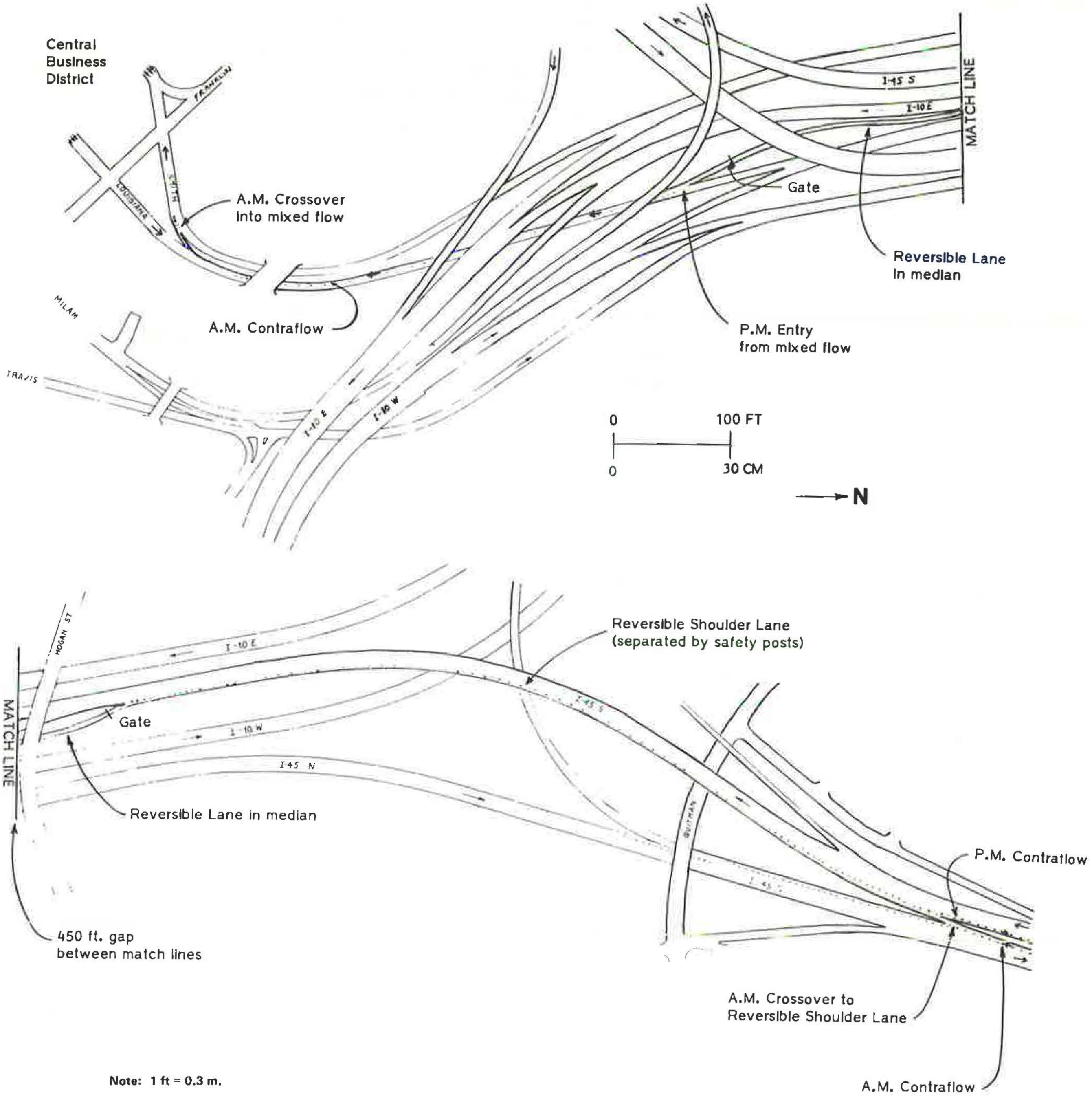
OPERATING PLAN

Setup and take-down procedures and supervision of the CFL are vested in the MTA Operations Department. Twice daily, 1200 pylons must be deployed from two specially designed stakebed trucks that are responsible for deploying pylons into every other hole. A third truck, a pickup driven by the crew supervisor, follows this platoon to ensure that all holes are filled and to activate switches for changeable message signs and signals. A total of 18 MTA employees organized into two shifts are assigned to deploy contraflow. These shifts include two wrecker drivers and two extras. The platoon is escorted by two units of the Houston Police Department.

The setup procedure requires the deployment to be performed with the flow of traffic. The take-down procedure is performed against (contra) the flow of traffic. This is done to minimize the disruption to traffic while providing protection to the crew and vehicles. Morning setup begins at 4:30 a.m. and is complete by 6:00 a.m. Take-down begins at 8:30 a.m. and is complete by 10:00 a.m. Similarly, evening setup occurs between 2:30 and 4:00 p.m. and takedown between 6:30 and 8:00 p.m.

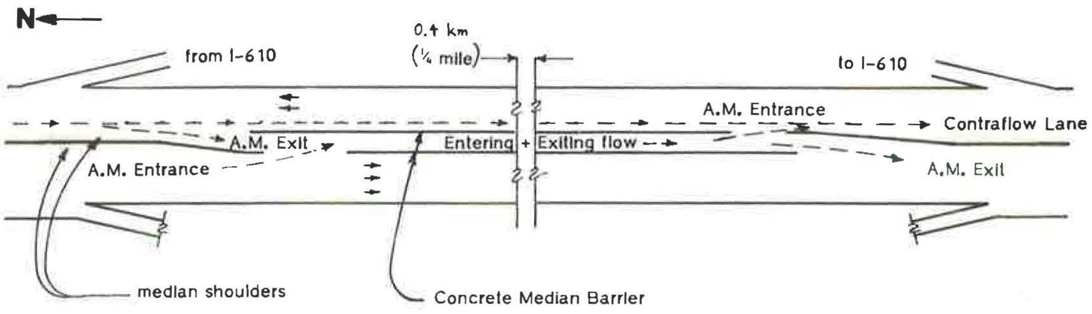
Labor cost for the CFL crew represents the major operational expenditure at approximately $30 000/month. Other operational costs, given in Table 1,

Figure 3. Downtown terminus to CFL.



Note: 1 ft = 0.3 m.

Figure 4. CFL midpoint crossover at I-610.



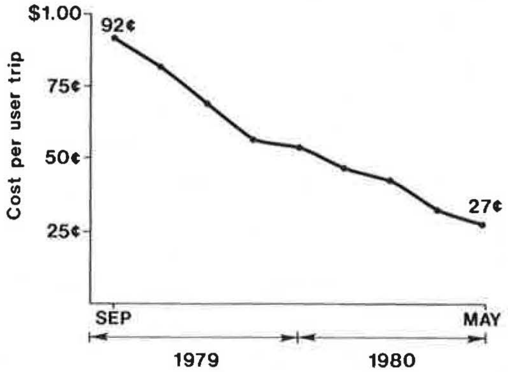
Design accomodates a reversal of operation in P.M. period

Table 1. CFL monthly operating costs.

Item	Cost ($)		
	September 1979	January 1980	May 1980
Setup/take-down operation			
Labor	30 000	33 000	33 000
Supplies	2 600	2 600	2 600
Enforcement	14 200	6 400	6 100
Wrecker (contract)	15 000	15 000	0[a]
Facility maintenance and repair	3 000	3 000	3 000
Total	64 800	60 000	44 700

[a] By April the MTA wrecker replaced temporary contract wrecker service.

Figure 5. Operating cost of CFL distributed among user trips.



encompass total monthly expenditures. Operating costs for the first year totaled about $650 000. If these expenses are distributed over the number of contraflow users, the resulting cost per user trip is shown in Figure 5. The decline in cost from $0.92 in September 1979 to $0.27 in June 1980 is a result of increased ridership and decreased operating requirements since project start-up.

Two basic groups of vehicles--vanpools and buses--are included as potential CFL users. In order for these vehicles to be authorized, rather rigid requirements are placed on potential users. Eligible vehicles include

1. All MTA transit vehicles,
2. Suburban commuter buses operated under contract to MTA,
3. Other full-size transit vehicles being operated on regularly scheduled services and approved by MTA pursuant to the requirements as listed, and
4. Vans designed to carry eight or more passengers, including the driver, and approved by MTA pursuant to the requirements as listed.

The following vehicle requirements must be met by vehicles under items 3 and 4 above before the vehicle can be authorized to use the CFL:

1. A van must have at least eight passengers registered, including the driver. The driver is responsible for keeping a monthly log of the pool's ridership, subject to MTA inspection.
2. Each vehicle and driver must maintain minimum insurance requirements as set forth by MTA.
3. MTA must be provided a current, valid copy of the insurance policy for each vehicle.
4. A valid Texas vehicle-inspection sticker must be displayed.
5. A valid contraflow authorization decal, provided on vehicle inspection by MTA, must be displayed on front and back windshields.
6. Authorized vehicles must be driven by a certified contraflow driver when on the CFL.

To be certified to drive an authorized vehicle on the CFL, every driver (including substitute and backup drivers) must

1. Have a valid state of Texas chauffeur's license,
2. Have a good driving record,
3. Complete MTA-sponsored contraflow training,
4. Maintain in possession at all times a CFL driver identification card, and
5. Abide by the rules and regulations explained during CFL training.

This unique approach to the authorization or restriction of vehicles to a transit preferential treatment greatly simplified enforcement and provided close controls over Houston's first step toward a regional transitway system. Unauthorized vehicles were identified if they did not display a permit and were deterred by police stationed at the entry points. The number of attempted violations has averaged about one per day.

CFL USE

During the first 44 weeks of project operation, CFL use increased steadily in absolute nunbers, as shown in Figures 6 and 7. Vehicle trips increased to 61

Figure 6. CFL peak-period vehicle movement.

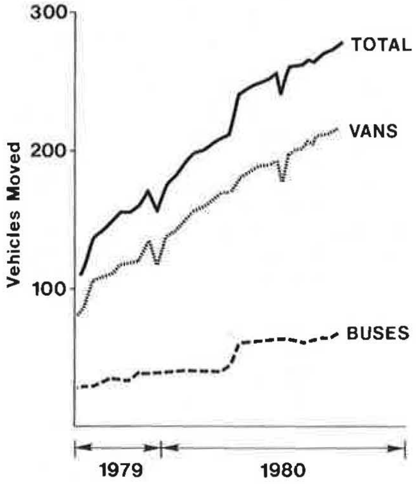
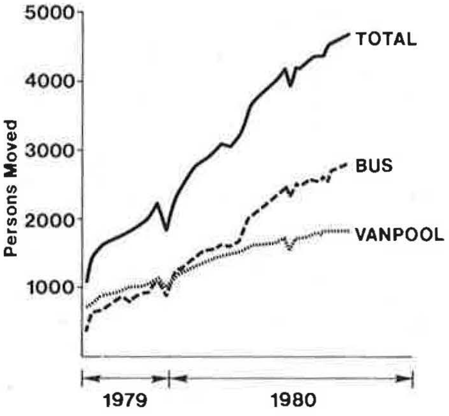


Figure 7. CFL peak-period person movement.



bus trips and 188 vanpool trips during each peak period, which represented more than a twofold increase since the project began operation. About 85 percent of the bus trips were made by contract carriers operating MTA express and park-and-ride routes. The remaining 15 percent involved private carriers making intercity and airport shuttle trips.

Person movement on the CFL initially reflected 1200 person trips/peak period, which was absorbed from previously operating vanpools and private bus service. By July 1980, total peak-period movement had grown to more than 4300 person trips, more than a threefold increase in patronage.

Steady increases in bus ridership have been attributed, in part, to the staggered openings of several new park-and-ride lots during the first 36 weeks. When CFL operation began, the only park-and-ride spaces available to bus commuters were 750 spaces at temporary lots. With the completion of all lots and the transfer of temporary operations to permanent sites, about 2400 parking spaces were made available to commuters.

Originally, the project was intended only for buses. It became apparent prior to opening, however, that bus volumes alone would not make the use of the lane adequately visible to oncoming traffic; thus, vanpools were identified as a supplemental, manageable group of high-occupancy users. An extensive corporate- and developer-sponsored vanpooling program in Houston helped contraflow achieve the immediate high level of use reflected in the first week with 85 vanpools. The ratio of vans to buses has remained rather consistent at about three to one. Person movement in vanpools originally exceeded that in buses, but by February this trend was reversed. Bus patronage in June represented 59 percent of all person movement on contraflow.

A strong peaking of demand on the CFL has been experienced, particularly among vanpool users. About 60 percent of the demand for contraflow has been concentrated within the peak hours. During isolated 15-min segments, more than 900 passengers were being transported on the lane. This peaking characteristic, unencumbered by the congestion constraint, has intensified since the project began. This intensity of use during the morning and afternoon peak hours has created the person-moving equivalent of 1.5 peak-direction freeway lanes. By June, the CFL was moving almost 25 percent of the peak-direction persons traveling the freeway during these hours.

The CFL, however, is still carrying less than 50 percent of its vehicle capacity during isolated periods of strong peaking. Because available capacity was apparent, after six months of project operation it was proposed that carpools be authorized to use the lane. The joint operation management team studied this proposal and determined that (a) authorized carpools could not be readily distinguished from violators, (b) management and authorization procedures would be difficult, and (c) the resulting impact could saturate the peak hours without improving visibility throughout the peak operating periods.

Whereas contraflow operation was planned to save users an average 15 min on each trip, a vanpool survey conducted after four months of operation indicated that 48 percent of users thought that they were saving 15 min or more in the morning period. Fully 74 percent expressed this same feeling about the evening period, and 34 percent of these indicated a saving of more than 20 min. These perceptions may be reasonable, since "before" travel speeds during the evening peak hours were 27 km/h (17 miles/h), which would represent a 34-min trip.

The CFL experienced two accidents involving authorized vehicles during operation periods the first year. Both accidents involved vehicles from adjacent off-peak-direction lanes losing control, skidding into the lane, and colliding with authorized vans. During this period, the CFL logged about 1 200 000 vehicle-km (750 000 vehicle-miles) of use.

Authorized vehicles became disabled 15 times on the lane during the first 44 weeks. A continuous-median shoulder along the CFL kept the majority of these disabled vehicles from disrupting lane operation.

IMPACTS ON OTHER FREEWAY USERS

Although the CFL removed about 2300 vehicles from peak-direction traffic during the first 10 months, latent demand and growth in the corridor have resulted in negligible impacts on peak-direction traffic volumes and travel speeds. In the off-peak direction, average speeds in the morning period were reduced about 13 percent to 77 km/h (48 miles/h), but no traffic congestion resulted. Impacts in the evening period, however, were significant in the northern portion of the project. Use of ramp metering was supplemented with temporary ramp closures at selected locations to improve unacceptable travel speeds (5). Controls on traffic flow forced some diversion to parallel frontage roads. This diversion helped to improve main-lane travel speeds to about 72 km/h (45 miles/h) but did not affect vehicle throughput in the freeway corridor. Most diverted traffic remained on the frontage roads and entered downstream of the critical segment.

Because of the significant evening off-peak-direction impact and initial low use of the CFL, after 12 weeks of operation the project was estimated to have had a net effect of increasing total delay time among users and nonusers of about 500 person-h daily. After ramp closures were implemented and higher use was reported by 31 weeks of operation, this characteristic had shifted to reflect a net decrease in delay time of about 720 person-h daily.

Freeway accidents reported for the period from August 1979 through February 1980 were not significantly increased from levels before project implementation (6). These levels may be compared with those for other contraflow projects in Table 2 (6,7).

Public acceptance of contraflow was considered imperative, although not decisive, to underscoring support for other subsequent high-occupancy-vehicle improvements in Houston. It was felt that any initial criticism could be overcome if the project catalyzed a perceptive shift to buses and vans while not forcing the off-peak-direction flow into levels of service worse than those for the peak direction. The regional press was objective, if not openly favorable, when CFL operation began. The safety of

Table 2. Accident rates for various contraflow projects.

Project	Before/After CFL	Period	Accidents (per million vehicle-km) Peak Direction	Off-Peak Direction
I-45, Houston	Before[a]	Morning	1.1	1.1
		Evening	2.1	1.1
	After[b]	Morning	0.9	1.4
		Evening	1.1	1.9
I-495, New Jersey[c]	After	Morning only	1.9	2.3
US-101, Marin County, California[d]	After	Evening only	1.4	2.4

[a] January 1979-August 1979 data.
[b] 1975-1976 data.
[c] 1972-1975 data.
[d] 1972-1976 data.

the project was occasionally questioned, and the press responded to several minor incidents within the first few months. After ramp closures were implemented, public criticism of the impacts on the off-peak direction was markedly reduced, although underuse of the lane during portions of the peak period continued to create some criticism.

CONCLUSIONS

After 44 weeks of project operation, the general conclusion of TSDHPT, MTA, and the public is that the North Freeway contraflow demonstration has proved successful. The level of use and its continued increase have exceeded expectations. The fact that about 2300 vehicles have been removed from peak traffic and that transit is providing a desired alternative to the automobile in this corridor has made a significant impact on the expectations for MTA's regional transitway goal.

It should be noted that this paper is an interim report. UMTA's SMD program sponsored an evaluation in October 1980 that provided an opportunity for more detailed data collection and evaluation. Other reports will be forthcoming. However, the information provided is sufficient to support the decision of MTA and TSDHPT to continue contraflow operation beyond the 18-month demonstration period until such time as a separated high-occupancy facility can be incorporated into the North Freeway.

REFERENCES

1. Feasibility of Contraflow Lanes on IH 45 (North Freeway). Texas State Department of Highways and Public Transportation, District 12, Houston, Jan. 1976.
2. UMTA Section 5 Capital: Preferential Treatment--Construction of a Contraflow Lane on North Freeway. Houston Office of Public Transportation, Aug. 1977.
3. Report on Evaluation of Size and Location of "Park and Ride" Facilities Near IH 45 North and the North City Limits of Houston. Texas State Department of Highways and Public Transportation, Houston, Houston Urban Project, Oct. 12, 1976.
4. Growth Options for Houston: Technical Report. Rice Center, Rice Univ., Houston, March 1978.
5. W.R. McCasland. Summary of Ramp Closure Results. Texas Transportation Institute, Texas A&M Univ., College Station, Jan. 17, 1980.
6. State Accident Statistics: Region 4. Education Service Center, Houston, Jan. 1978-Feb. 1980.
7. Beiswenger, Hoch, and Associates. Safety Evaluation of Priority Treatment Techniques for High-Occupancy Vehicles. Federal Highway Administration, U.S. Department of Transportation, 1979.

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Evaluation of a Contraflow Arterial Bus Lane

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In 1979, the city of Madison, Wisconsin, conducted a 90-day trial experiment in which a contraflow arterial bus lane was closed and all buses were rerouted into mixed-traffic lanes on a parallel arterial. The findings and conclusions of that experiment, as well as comments on generalizable conclusions that might be drawn from the Madison experience, are presented. Evaluation criteria included traffic performance, safety, transit revenue, transit ridership, and environmental impacts. The study findings supported the conclusion that the permanent closing of the bus lane would be undesirable principally because of anticipated increases in bus accidents and higher rates of fuel consumption and pollutant emissions.

In 1966, the city of Madison, Wisconsin, constructed a contraflow bus lane along a 0.9-mile section of University Avenue in conjunction with the initiation of one-way traffic flow on University Avenue and West Johnson Street, an adjacent arterial (1). As Figure 1 shows, West Johnson Street provided four lanes for eastbound traffic (parking was prohibited on both sides). University Avenue provided four lanes for westbound traffic plus one lane to be reversed for eastbound bus service. The one-way pair of arterials serves as the principal access to the Madison central business district (CBD) from extensive residential areas on the west side of the city. Both arterials also pass through the heart of the 40 000-student Madison campus of the University of Wisconsin.

The University Avenue contraflow lane functioned without difficulty until March 1, 1967, when a student walked into the side of an eastbound bus and was seriously injured. Considerable discussion ensued, and there were claims that the bus lane was ill-advised and that eastbound bus operations should be moved to Johnson Street. This proposal was presented to the Madison Common Council on May 23, 1967, where it was rejected by unanimous vote. Following further study and discussion over the next several years, on May 5, 1970, the Common Council again rejected a proposal to move eastbound buses to Johnson Street. In the years following 1970, the contraflow lane was used by increasing volumes of bicyclists but nevertheless operated successfully and without major incident. In recent years, University Avenue and West Johnson Street have each carried more than 20 000 vehicles/day. In a given hour, as many as 40 buses share the contraflow lane with as many as 300 bicycles. In 1976, the right curb lane on University Avenue was designated as a reserve lane for buses, bicycles, and right-turning vehicles.

Then, in 1978, a controversy arose. After extensive evaluation of alternative design projects for the overall improvement of the University Avenue-Johnson Street corridor, the Madison Common Council rejected the entire set of candidate alternatives and expressed a renewed interest in relocating eastbound bus operations to Johnson Street. The principal issues underlying the relocation sentiment were closely related to the design features of the proposed University Avenue improvements, the heavy use of the bus lane by bicyclists, and the large concentrations of pedestrian movements crossing University Avenue during university class-change times. Groups of students and downtown residents were vocal in their opposition to the bus lane because of

Figure 1. Contraflow bus lane and inbound bus routes.

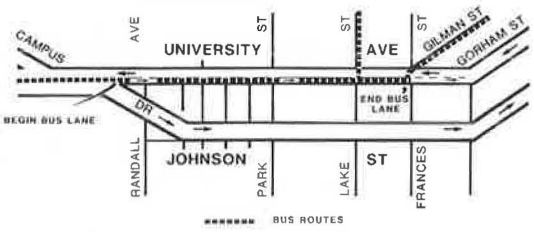
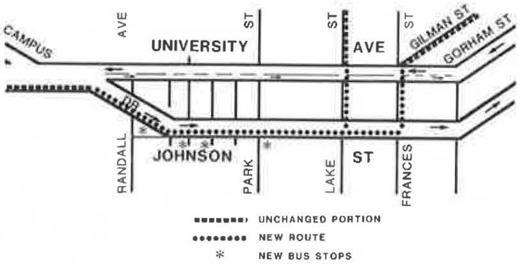


Figure 2. Inbound bus routes during 90-day trial.



1. Perceived safety problems associated with bicycle use of the contraflow bus lane and the large volume of pedestrian movements,
2. The desire to avoid widening University Avenue (this was a requirement of the recommended design alternative, which was to have provided exclusive lanes for both bicycles and buses), and
3. A general sentiment against any proposal that would directly or indirectly benefit motorists.

As a result of the controversy and intense political pressures, the Madison Department of Transportation (DOT) was directed to develop a plan for testing the feasibility of relocating eastbound bus routes from the University Avenue contraflow lane to the mixed-traffic lanes on West Johnson Street. A plan for a 90-day trial and impact evaluation was subsequently adopted and implemented against the recommendation of the city director of transportation. The purpose of this paper is to present the findings and conclusions of that experiment (2).

EXPERIMENTAL PLAN

The 90-day trial relocation of eastbound buses from the University Avenue contraflow lane to the mixed-traffic lanes on Johnson Street was initiated on April 15, 1979 (see Figure 2). Implementation of the plan required the removal of five bus stops on the south side of University Avenue and the installation of four bus stops on West Johnson Street. On the east side of Frances Street and on the west side of Lake Street between University Avenue and Johnson Street, it was necessary to remove 13 on-street parking spaces to provide adequate vehicle clearances (Figure 2). During the trial, the contraflow lane was closed to all traffic except eastbound bicycles. Extensive publicity through print and electronic news media, as well as special survey and monitoring activities, preceded the trial. Data collection and analysis were the result of a cooperative effort by staff of the Madison DOT, the Wisconsin DOT, and the University of Wisconsin Department of Civil and Environmental Engineering.

The scope of the experiment was limited to a study of the short-range operational, safety, economic, and environmental impacts of the proposed change in transit routing. The following evaluation criteria were agreed on and included:

1. Traffic performance measures--Travel time and delay through the corridor by mode would be compared by using both field data and simulation data generated by the TRANSYT/6C computer model (3,4).
2. Safety measures--A comparison of traffic accidents by type of accident occurring within the University Avenue and Johnson Street corridors would be made for comparable time periods before and during the trial.
3. Revenue measures--Special farebox meter readings would be taken on appropriate bus lanes entering and leaving the University Avenue-Johnson Street corridor and at the end of every run for comparable time periods before and during the trial.
4. Ridership--The special farebox meter readings would provide an indication of any systemwide changes in ridership. A survey of passengers boarding and leaving buses within the corridor would also be undertaken before and during the trial to determine the attitudes of and any effects on transit system users within the affected corridor. A mail-back questionnaire would be used in the survey.
5. Environmental measures--Air-quality and fuel-consumption impacts would be evaluated by using the TRANSYT/6C computer model.

The decision to use the TRANSYT/6C model as a supplement to the field data-collection studies was made on the basis of expediency and the need to generate certain performance and environmental measures that would otherwise have been impossible to obtain. For the simulation analyses, two alternative bus-operation plans (see Figures 3 and 4) were evaluated under both morning and evening peak-hour conditions (5). The first alternative represented the base, or before, condition in which eastbound buses operate in the University Avenue contraflow lane. It was assumed that the existing contraflow lane was widened and resurfaced as proposed in the recommended University Avenue reconstruction plan. The second alternative represented the experimental operating strategy in which eastbound buses were temporarily relocated to the mixed-traffic lanes on Johnson Street. The network over which traffic flow was simulated consisted of the University Avenue-Johnson Street corridor from Breese Terrace to State Street. This included all connecting streets as well as the intersection at Park and Dayton Streets.

Figure 3. Contraflow bus-operation plan.

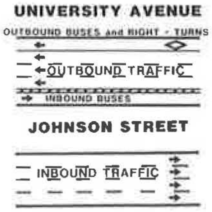


Figure 4. Mixed-flow bus-operation plan.

Table 1. Bus travel-time data.

Peak Period	Path	Average Time (min) Before Rerouting[a]	Average Time (min) During Rerouting[b]	Difference	Change (%)
Morning	Campus Drive to Gilman and State	5.8	5.1	-0.7	-12.1
	Park Street to Gilman and State	3.3	3.6	+0.3	+9.1
Evening	Campus Drive to Gilman and State	7.9	7.1	-0.8	-10.1
	Park Street to Gilman and State	4.5	5.2	+0.7	+15.5

[a] April 11, 1979.

[b] April 25, 1979.

Table 2. Impact of relocation of eastbound bus operations on average travel time along selected paths.

Path	Morning Peak Period Before Condition (min)	Morning Peak Period Change (%)	Evening Peak Period Before Condition (min)	Evening Peak Period Change (%)
Automobile				
Campus Drive and University Avenue to Johnson and Broom Streets	2.77	+2.2	3.05	+2.0
Bus				
Campus Drive and University Avenue to Frances Street and University Avenue	4.49	+5.6	4.78	+13.0
Campus Drive and University Avenue to Lake Street and University Avenue	4.00	+12.8	4.12	+33.3

Table 3. Impact of relocation of eastbound bus operations on network travel time.

Vehicle Category	Morning Peak Period Travel Time in Before Condition (vehicle-h/h)	Morning Peak Period Change (%)	Evening Peak Period Travel Time in Before Condition (vehicle-h/h)	Evening Peak Period Change (%)
Automobile	238.88	+0.9	351.35	–
Bus	6.17	+6.4	7.35	+12.8
Total	245.05	+1.0	358.70	+0.3

Table 4. Accident data: four-year average and April 15-June 15, 1979, trial period.

Category	Four-Year Average University Avenue	Four-Year Average Johnson Street	1979 University Avenue	1979 Johnson Street
Accidents				
Total	30.75	27.25	18	23
Injury	7.75	6.0	2	6
Vehicle miles (000 000s)	2.052	2.117	1.726	1.849
Accident rate (%)	15.0	12.9	10.4	12.4

FINDINGS

The results of the various field studies and the simulation analyses are summarized below. Examination of traffic counts conducted before and during the experiment revealed no significant changes in automobile, pedestrian, and bicycle flow patterns. The only changes involved the buses that were rerouted to West Johnson Street (Figure 2).

Traffic Performance Measures

Field observations of bus travel times during the peak hours (6:00-9:00 a.m. and 3:00-6:00 p.m.) indicated that eastbound buses that traveled the entire corridor length had slightly shorter travel times on West Johnson Street than on University Avenue in both morning and evening peak hours (see Table 1). Buses that entered the corridor at Park Street had slightly longer travel times on Johnson Street than on University Avenue. This suggested that bus travel times are faster on Johnson Street in spite of the delays caused by the required weaving and turning maneuvers between Park and State Streets. However, the comparison was misleading in the sense that the before data were not representative of the expected performance of the contraflow lane under the proposed corridor reconstruction plan. The before data measured in the field included the effects of an extremely poor pavement surface in the contraflow lane, two more traffic signals on University Avenue than on Johnson Street, the presence of bicycles in the contraflow lane (which is too narrow for buses and bicycles to pass each other), and one more bus stop on University Avenue than on Johnson Street.

The simulation analyses that were conducted by using the TRANSYT/6C model permitted a number of these factors to be controlled. Assuming comparable pavement surface quality, no bicycles in the contraflow lane, and one less bus stop on Johnson Street than on University Avenue, it was found that both automobile and bus travel times through the corridor could be expected to increase should the contraflow bus lane be abandoned (see Table 2). The expected impact of closure of the contraflow lane on overall network travel time for both automobiles and buses is given in Table 3. It was again apparent that the contraflow lane would reduce travel times, especially for buses.

Safety Measures

Table 4 provides a summary of traffic accidents and vehicle miles of travel that occurred during the 90-day trial and comparable time periods in the four previous years. All reported traffic accidents that occurred along University Avenue and West Johnson Street between Bassett Street and Babcock Drive were mapped and analyzed as part of the study. Although the data suggest that safety would be enhanced by rerouting buses back into mixed traffic on West Johnson Street, a chi-square test of the difference in the number of before and after accidents revealed that the differences indicated in Table 4 were not statistically significant. The 90-day trial was simply too short a time period on which to test safety impacts in a before-and-after type of comparison.

Table 5. Rates of bus-involved accidents.

		Bus Accidents		
Street	Number of Bus Miles	Type	Number	Number per 100 000 Bus Miles
Johnson Street eastbound	50 525^a	Bus/bicycle	1	13.8
		Bus/automobile	6	
		Total	7	
University Avenue				
Eastbound	196 960	Bus only	2	5.1
		Bus/pedestrian	5	
		Bus/automobile	3	
		Total	10	
Westbound	259 372	Bus/bicycle	1	5.4
		Bus/automobile	13	
		Total	14	

^{a}Primarily university campus buses.

As an alternative approach to the safety issue, rates of bus-involved accidents for the four-year period ending in 1978 were examined (see Table 5). During this time period, there were buses operating in the mixed-traffic lanes on Johnson Street, in the contraflow (eastbound) bus lane on University Avenue, and in the reserved (westbound) bus lane on University Avenue. The data clearly suggest that bus operations in both the eastbound contraflow lane and the westbound reserved bus lane were substantially safer than bus operations in the mixed-traffic lanes on Johnson Street. Moreover, by using a rate quality control test, these differences were found to be statistically significant. The reason for the better safety record can be directly attributed to a reduction in traffic conflicts and stream friction made possible by the separation of buses and automobiles.

Revenue and Ridership Measures

The effect of the trial on transit revenue and ridership was seen as one of the most important evaluation criteria. However, because of yearly variations in ridership, a fare increase that went into effect on January 1, 1979, and other factors that influence ridership, it was not possible to determine whether or to what extent the 90-day trial had any direct effect on ridership or revenue.

Reliance therefore had to be placed on the transit-user survey conducted before and during the trial. The survey involved the distribution of 4777 mail-back questionnaires to bus passengers (2756 before and 2021 during the trial) in the University Avenue-Johnson Street corridor. The before survey was conducted on Thursday, April 12, 1978, and had a 49 percent response rate. The during survey was conducted on Thursday, April 26, 1979, and had a 54 percent response rate. In each case, surveys were distributed during the hours of 7:00-9:00 a.m., 10:00 a.m.-noon, 3:00-5:00 p.m., and 7:00-9:00 p.m. The during survey was conducted only two weeks after the before survey so that rider characteristics, which change with the approach of examination time and the end of the university school year, would remain constant. There was also the possibility of a work stoppage in connection with the expiration of the bus-driver contract on May 1, 1979.

The results of the transit-user survey are summarized below:

1. Frequency of use--Approximately 88 percent of the respondents both before and during the trial stated that they used the bus at least three times per week, which indicates the very large percentage of regular bus riders with destinations in the subject corridor.

2. Street crossings--Before the trial, 19.3 percent of the respondents had to cross both University Avenue and Johnson Street to get to or from their destinations. During the trial, 65.4 percent had to cross both streets. The two surveys correlated well to indicate that 70 percent of riders have destinations north of University Avenue, 17 percent have destinations south of Johnson Street, and 13 percent have destinations between Johnson Street and University Avenue.

3. Walking distance--There was an increase in overall walking distance for bus users as a result of the trial, as indicated in the following table:

No. of Blocks Walked	Respondents (%)	
	Before Trial	During Trial
0-2	67.9	51.3
3	16.9	26.1
≥4	15.2	22.6

4. Convenience--Before the trial, 94.4 percent of the respondents rated the service on University Avenue as either good or very good. Only 3.7 percent of the respondents felt the service was poor or very poor. This very favorable perception of service was severely affected by the trial. Only 53.1 percent rated Johnson Street good or very good, and 43 percent rated Johnson Street service as poor or very poor. This represented a significant difference in the respondents' perception of convenience.

5. Route preference--Before the trial, 78.3 percent of the respondents indicated a preference for the University Avenue contraflow lane whereas 14.1 percent indicated a preference for Johnson Street. During the trial, 66.4 percent of the respondents continued to indicate a preference for the University Avenue route while 25.8 percent indicated a preference for the Johnson Street route. Preference for the University Avenue route continued very strong among the more frequent bus users; 82 percent of the respondents who rode three or more times per week preferred the contraflow lane.

Environmental Measures

The TRANSYT/6C computer model that was used to generate traffic performance data for the corridor network also produced estimates of fuel consumption and exhaust emissions by mode. These data are summarized in Table 6 and are based on the same assumptions previously discussed regarding the characteristics of the before-and-after network. (The ranges of variance noted in the footnotes to Table 6 are the results of varying selected computer input parameters. All other values were found to be stable estimates.)

Table 6. Impact of relocation of eastbound bus operations on network fuel consumption and pollutant emissions.

Measure of Effectiveness	Morning Peak Period Before Condition	Morning Peak Period Change (%)	Evening Peak Period Before Condition	Evening Peak Period Change (%)
Fuel consumption (gal/h)				
Automobile	453.53	-	630.06	+0.6
Bus	18.82	-7.3	21.13	+4.3[a]
Total	472.35	-0.3	651.19	+0.6
Emissions (kg/h)				
Hydrocarbons				
Automobile	24.24	+0.5	37.17	+0.7
Bus	0.66	+8.2[b]	0.81	+17.3
Total	24.90	+0.6	37.98	+1.0
Carbon monoxide				
Automobile	258.27	+0.4	408.68	+0.8
Bus	6.67	+13.8[c]	8.66	+21.1
Total	264.94	+0.7	417.34	+1.2
Nitrogen oxides				
Automobile	12.47	-0.2	18.62	+0.2
Bus	0.28	-7.5[d]	0.27	+5.5[e]
Total	12.76	-0.5	18.89	+0.2

[a] Actual increase may vary from 1.2 to 7.5 percent.
[b] Actual increase may vary from 6.1 to 10.3 percent.
[c] Actual increase may vary from 11.7 to 16.0 percent.
[d] Actual decrease may vary from 3.6 to 12.9 percent.
[e] Actual increase may vary from 3.6 to 7.4 percent.

With the exception of fuel consumption and emissions of nitrogen oxides during the morning peak period, the before condition yields the best overall performance. The degradation in bus performance under the relocation strategy is the most apparent impact, especially during the evening peak period. Although the percentage reduction in automobile efficiency is relatively small, when examined in absolute terms these changes can exceed those associated with buses. For example, in the case of fuel consumption during the evening peak period, the percentage increase in bus fuel consumption under the relocation plan is about seven times as great as the percentage increase in automobile fuel consumption. However, in terms of gallons consumed per hour, the impact on automobile traffic is about four times greater than that on buses.

CONCLUSIONS

The purpose of this study was to determine the feasibility of relocating eastbound buses from the contraflow lane on University Avenue to mixed-traffic conditions on West Johnson Street. Based on the findings discussed above, it was recommended to the Madison Common Council that relocating buses to West Johnson Street would not be desirable because

1. The historical (pretrial) bus accident rate is substantially higher on Johnson Street than on University Avenue,
2. There is no evidence that overall traffic safety could be significantly improved by relocation,
3. Seventy percent of the bus users in the corridor would be forced to cross an additional major street and walk further to reach their destinations,
4. There could be a long-range negative impact on transit ridership because of longer walking time and distance for a majority of bus users in the corridor,
5. Overall fuel consumption and vehicle emissions would be higher, and
6. Relocation would result in no significant measurable improvement to the transit system.

It was further stated that the study results reaffirmed the original contention and basis for constructing the contraflow lane in 1966--namely, that the contraflow lane does in fact provide more convenient transit service, more efficient overall transit and traffic operations, and a higher level of safety than mixed traffic flow on West Johnson Street.

The current status of the bus-lane controversy remains unresolved. Eastbound buses still operate in the mixed-traffic lanes on West Johnson Street even though the 90-day trial ended more than a year ago. The city will not be making any changes until a completely new set of corridor improvement alternatives is evaluated.

Deriving generalizable conclusions from the Madison experience is difficult. Although the city is known for its innovative efforts in transportation, it must also contend with a politically active, and often unpredictable, constituency quite unlike those of most other cities. If there is a lesson to be learned, it is that relatively short contraflow lanes are not likely to produce performance improvements of a magnitude that will necessarily outweigh the possible disbenefits perceived by influential special-interest groups. Nevertheless, the results of the 90-day trial and the various analyses did tend to confirm the relative advantages of contraflow bus lanes in congested areas.

REFERENCES

1. H.S. Levinson, W.F. Hoel, D.B. Sanders, and F.H. Wynn. Bus Use of Highways: State of the Art. NCHRP, Rept. 143, 1973.
2. University Avenue-West Johnson Street 90-Day Trial Bus Route Evaluation Study. Madison Department of Transportation, Madison, WI, Final Rept., Nov. 1979.
3. D.I. Robertson. TRANSYT: A Traffic Network Study Tool. Road Research Laboratory, Crowthorne, Berkshire, England, Rept. LR 253, 1969.
4. TRANSYT/6C Model Workshop. Institute of Transportation Studies, Univ. of California, Berkeley, Student Workbook, 1977.
5. W.D. Berg and T.N. Notbohm. Traffic Performance and Transit Ridership Impacts of Closing the University Avenue Contra-Flow Bus Lane. Department of Civil and Environmental Engineering, Univ. of Wisconsin, Madison, Feb. 1980.

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Use and Consequences of Timed Transfers on U.S. Transit Properties

MICHAEL NELSON, DANIEL BRAND, AND MICHAEL MANDEL

A recently completed study conducted for the Transportation Systems Center examined the current use and impacts of a total of 11 transfer policy options (including timed transfers) on U.S. transit properties to identify the situations or settings in which particular transfer policies can most beneficially be applied. Data for the study were drawn from a series of telephone and on-site discussions with experienced transit professionals on 39 different properties. The information resulting from these discussions has been supplemented with a limited amount of site-specific quantitative data and references to the literature as appropriate. The findings of that study regarding timed transfers are presented. Implementation of timed transfers can involve adjustments of headways, route lengths, and/or layover times as well as provision of suitable space, facilities, and information to permit the easy interchange of passengers between buses. Transit-property size is the principal criterion for the applicability of timed transfers, serving as a proxy for headway reliability, service frequency, and the number of buses meeting at one time. Small properties are generally able to use timed transfers at their main transfer point, whereas larger properties may only be able to use this option on a relatively more limited scale. Ridership gains on the order of 5-12 percent may be realized under some circumstances solely from the implementation of timed transfers. Overall, timed transfers appear to be a cost-effective way of increasing service and ridership in many settings without necessarily increasing costs.

A timed transfer is defined as any set of operator actions that provides for vehicles on different routes to meet at regular intervals to exchange transferring passengers. The simplest form of timed transfers involves only two routes. At the other end of the complexity scale is the extensive use of timed transfers (also known as "pulse scheduling"), where vehicles on all (or most) routes are scheduled to meet at the major transfer point nearly simultaneously, hold until all the vehicles have come in, and then leave together. When this occurs at regular intervals, the effect is as if the vehicles were pulsing.

In between these extremes are two other types of timed transfers. When pulse scheduling of buses is used only in the evening or off-peak hours, with low service frequencies and possibly long layovers at the transfer point, it is commonly called a "lineup". Unlike pulse scheduling, lineups are found in larger cities. Another variant of timed transfers, "neighborhood pulse", is also found on large properties. It involves coordinating the schedules of neighborhood bus circulator routes to make travel within a section of a city easier.

This paper examines situations in which these variants of bus timed transfers are used and the operator actions associated with implementing them. (Examples of simple timed transfers in which rail is the connecting mode were also found, but this practice is quite uncommon and is not addressed further in this paper.) The effects of timed transfers on operator costs, user satisfaction, ridership, and revenue are then described, and conclusions are drawn concerning the applicability of timed transfers in different settings.

The findings in this paper are drawn from a recently completed study of 11 transfer policy options (including timed transfers) on U.S. transit properties (1). Data for the study were drawn largely from an extensive series of telephone and on-site discussions with experienced transit professionals on 39 different properties, 16 of which used timed transfers of some sort, as indicated below:

Type of Timed Transfer	Property
Simple	Albany, New York
	Washington, D.C.
Pulse scheduling	Fresno, California
	Lafayette, Indiana
	Brockton, Massachusetts
	Westport, Connecticut
	Lewiston, Maine
	Haverhill, Massachusetts
Lineup	Knoxville, Tennessee
	Portland, Oregon
	Columbus, Ohio
	Memphis, Tennessee
	Toledo, Ohio
	Albany, New York
Neighborhood pulse	Denver, Colorado
	Portland, Oregon

This sample clearly does not include all properties that use some form of timed transfers, nor was it a random sample designed to yield statistically representative results. Rather, the survey was designed to yield the greatest possible amount of information on different operating environments and practices as was feasible with a limited sample size.

CURRENT PRACTICES

As the following table indicates, the demand for transferring on a transit property is clearly related to the type of transfer policy adopted:

Use of Timed Transfers	Transfer Rate (%)		
	Average	Low	High
Extensive	28	18	50
Not extensive	18	5	33

As the table shows, bus properties that currently use timed transfers extensively have an average transfer rate of 28 percent, whereas properties that do not use timed transfers extensively have an average transfer rate of approximately 18 percent. Furthermore, when the properties that use timed transfers extensively (all of which are small) are separated from the remaining small and large properties, the suggested relation between ridership and the use of timed transfers becomes even more pronounced:

Type of Transit Property	Transfer Rate (%)		
	Average	Low	High
Large	20.3	10	33
Small			
No use of timed transfers	11.8	5	20
Use of timed transfers	28.0	18	50

It should be noted, though, that the causal relation here is not clear. Timed transfers may increase transfer ridership through a reduction in transfer time but, conversely, the existence of travel patterns that result in a high transfer rate may make it more likely that a property will institute timed transfers. Thus, it cannot be concluded with certainty that the use of timed transfers will always cause substantial increases in transfer ridership. Rather, it is necessary to consider carefully the circumstances surrounding each possible application of timed transfers before ridership and other impacts can reliably be assessed.

Simple Timed Transfers

Simple timed transfers, where buses on two routes are guaranteed to meet regularly, illustrate the basic principles of timed transfers. Simple timed transfers are used on many properties, from the smallest to the largest. They are most commonly used in the evening when both routes have low frequencies. Simple timed transfers, almost by definition, are more likely to be found at outlying transfer points where few routes may meet. However, their use is not restricted to any particular setting.

In order to implement simple timed transfers, schedules must be adjusted so that buses arrive at the transfer point at the same time. There are differences, though, in the way operators handle the unavoidable problems of schedule unreliability. Some operators have the buses lay over for 2-5 min at the transfer point, assuming that such a layover provides enough of a cushion to ensure that the buses will meet. Other operators use "dynamic control" to hold the first bus until the second bus arrives, if the second bus has transferring passengers. (This real-time modification of schedules is usually accomplished through verbal communication by radio, although other communications media are sometimes used.) The problem with "static control", where each bus is simply scheduled to hold until the other arrives, is that, if one bus breaks down or is extremely late, the schedule of the second bus is needlessly disrupted. Therefore, true static control is rarely used and a limit is typically placed on the length of time spent waiting. All of these operator actions, however, have the common objective of guaranteeing transfers with a low wait time between two routes.

Pulse Scheduling

Pulse scheduling, or extensive timed transfers, is the type of timed transfer that has the most far-reaching operational consequences. The transit properties that currently use this option are extremely diverse, serving a wide variety of communities all over the United States, including college towns, industrial cities, and bedroom suburbs. Table 1 gives service, route, and scheduling data (based on operator interviews, timetables and maps from each property, and data from the American Public Transit Association) for several of these properties that participated in the study sample. Annual ridership among these properties ranges from the tens of thousands to more than 4 million. Fleet sizes range from 3 to about 100 buses and service-area populations from less than 30 000 to more than 300 000. It is interesting to note, however, that virtually all of the pulse properties offer free transfers. This may reflect both a "philosophy" on pulse properties of simplifying and reducing the burden of transfers and an effective marketing approach.

Important aspects of pulse transfers include service frequency, routing, schedule adherence, space for buses to meet, and operator information policies. Since all buses are meeting, it is possible to speak of a "pulse frequency" of which all route frequencies are a multiple. The most common pulse frequency is 30 min. Other pulse frequencies such as 35 and 45 min (with some buses meeting in between the major pulses) are also in use, as Table 1 indicates. These frequencies typically do not change much between the peak and off-peak periods, although some properties halve the frequency in the evenings and on weekends.

Given the ranges of headways that are found on different properties and the different ways of making them compatible, it is somewhat surprising to find that 30 min is almost uniformly perceived as the preferred pulse frequency. Many operators believe that a 30-min headway makes the transit system easier to understand. In addition, 30-min headways are quite compatible with clock-face scheduling. These reasons are consistent with the design of timed transfers as a popularly supported, easily understood, and not easily disrupted public transit system. Virtually all of the properties that use a pulse other than 30 min originally implemented pulse at a 30-min frequency and later modified it because of schedule unreliability, increases in ridership that led to longer running times, or other site-specific reasons.

Because of the need for a uniform frequency, implementation of timed transfers may involve reducing frequency on some lines, which would reduce level of service, or increasing frequency on others, which is costly. Both possibilities require making "artificial" changes to the schedule that may be wholly unsatisfactory in some settings. Forcing a wide variety of routes to meet in time and space may be essentially infeasible, especially in large cities. In the opinion of one experienced transit professional, "In large cities, crosstowns are better and cheaper, too."

The need for all or most routes to have the same headway in turn constrains the routing of buses. When implementing pulse scheduling, many properties find that their natural routes are too long and that pulse limits their route miles. A typical remedy is to cut short the ends of the routes. In addition,

Table 1. Characteristics of sample U.S. transit properties that use pulse scheduling.

City	Population of Service Area (000s)	Transfer Charge (cents)	Total Annual Ridership (000s)	Approximate No. of Buses in Fleet	Approximate No. of Routes in System[a]	Pulse Frequency[b] (min)	No. of Buses Meeting Each Pulse
Eugene, Oregon	210	0	2860	67	20	30	12
Lafayette, Indiana	110	5	1100	29	14	30	14
Brockton, Massachusetts	100	0	2790	32	16	45[c]	15
Westport, Connecticut	30	0	640	25	7	35	7
Fresno, California	310	0	4400	99	21	30	12[d]
Lewiston, Maine	70	0	460	18	9	30	9
Everett, Washington	50	0	1020	18	12	30	11
Haverhill, Massachusetts	50	0	90	3	6	30[e]	3

[a] Not including express routes.
[b] Generally constant throughout the day.
[c] Some routes meet every 22.5 min at an intermediate pulse.
[d] With "syncopated pulse", the buses are divided (seven and five) between two adjacent pulse points.
[e] Because three buses run six routes, each route has a 60-min headway.

through routing can be used to achieve headways that do not divide evenly into route run times. On the other hand, several properties have routes that are too short. The operator response to this problem is typically to increase layovers to equalize running times or to extend the routes by loops or other means, thus adding area coverage.

In practice, the choice of a pulse frequency can never be made independently of routing decisions. A major influence in the balance between frequency and routing is the size and shape of the relevant transit district. Lafayette, Indiana, and Brockton, Massachusetts, are two pulse cities that have relatively compact service areas and thus have no trouble operating a 30-min pulse with good loop area coverage. Another pulse property, Everett, Washington, had difficulty expanding the length of its routes because the service area is long and thin and the central business district (CBD) is not in its geographic center. In general, properties whose CBDs are in the geographic center of the relevant area find it easier to pick an appropriate pulse frequency and then equalize running times on different routes based on the size of the area.

Ensuring schedule adherence is a major problem for pulse properties. The reasons for schedule unreliability tend to be the same as those on nonpulse properties: traffic congestion, breakdowns of new buses, and interference from trains. However, since the essence of timed transfers is to ensure that transferring passengers make connections, maintaining schedule adherence is more important on pulse properties.

Two strategies are available for coping with problems of schedule reliability on a pulse system. The first strategy is to build extra layover time into the schedule. Most pulse systems use layovers of 5 min or less out of each half-hour. Use of additional layover time is limited if the same schedule is to be used for both peak and off-peak periods. That is, if long enough layovers are added to absorb peak-hour unreliability, there will be costly unused layovers during the off-peak period. However, layovers of 5 min or less are usually not sufficient to handle all schedule-adherence problems.

Therefore, almost all pulse properties also use the second possible strategy, dynamic control, to mitigate problems with schedule reliability at the pulse point. In general, buses will hold for a maximum of 3-6 extra min for late buses before leaving the pulse point. If the late bus is radio equipped, the driver can inform the dispatcher or starter which routes will be receiving transferring passengers so that buses can be selectively released.

Typically, "lengthy" detention of buses through dynamic control is used most effectively during off-peak hours, during the last pulse of the day, and toward the end of the peak. Its use is avoided at the beginning of peak hours because during the peak buses have difficulty catching up to the schedule if they have been held any length of time. It is generally thought to be better to let one or two peak-hour buses miss the pulse than to disturb the rest of the system. On the other hand, it is very important on the last trips of the day to ensure that no one is stranded.

Some properties use short layovers and static control (holding "blindly" for up to 5 min) to deal with schedule uncertainty. These operators, who do not have radios, sometimes encounter a situation that might be called "disintegrating pulse". Because layovers are short and buses may be detained inefficiently, routes on which traffic congestion is bad may not be able to stay on schedule and are simply dropped from the pulse.

Another important requirement of pulse scheduling is the provision of space for buses to meet at the pulse point. Most pulse properties have a single pulse point that is located in the CBD. Typically, 9-12 buses occupy the pulse point at each pulse, although as many as 15 or as few as 3 buses have been observed in practice, depending on the size of the system. These numbers refer only to the buses meeting the pulse; pulse points may have unsynchronized routes that terminate there as well.

There is a need to keep all pulsing buses close together for the benefit of riders and for better control of the pulse. Buses are most often distributed over one or two blocks along a street. This may create problems for some passengers, since it is far enough to cause them to miss their buses. In general, though, the use of on-street stops is not viewed as intolerable by operators. Of the pulse properties participating in this study, only Brockton has an off-street facility and that was only opened in March 1979.

Two other properties have adopted atypical solutions to the problem of arranging buses at the pulse point. Because of space limitations, Fresno, California, had to adopt what might be called syncopated pulse, where the buses at one pulse point are routed so that they pass by the other pulse point both coming in and going out. The buses that terminate at the first pulse point drop off passengers at the second pulse point just before it pulses and pick up passengers at the second pulse point just after it pulses. In this way, passengers can make their transfers within a reasonably short time without all of the routes having to terminate at the same spot.

The second property that has used an unusual pulse-point arrangement is Lafayette. Until January 1979, Lafayette had two pulse points, one in the CBD and a second at Purdue University. The two pulse points were approximately 1 mile apart across a river and connected by a shuttle route that met both pulses. This arrangement was originally instituted to increase coverage to the west side of town and to keep large numbers of buses off the single major bridge over the river. However, Lafayette went back to using a single pulse point in the CBD in January 1979 because of problems in adhering to schedules.

This experience raises the problem of conflict between pulsing buses--both parked and moving in platoons--and automobile traffic. In many cases, some traffic engineering work and cooperation from the police are necessary to ensure smooth operations. These aids, and the possible tendency of automobiles to avoid "pulse streets", tend to keep traffic-congestion problems to a minimum.

Pulse properties vary considerably in the degree to which they publicize their use of pulse scheduling. Several properties make it clear from their schedules that pulse scheduling is a keystone of their system. Other properties place some emphasis on pulse scheduling without making it the dominant feature of the system. Finally, there are some properties that do not highlight their use of pulse scheduling at all. This last group includes systems that historically have had some sort of timed transfers or clock-face scheduling and do not regard it as an especially distinctive feature.

Other Types of Timed Transfers

The other variants of timed transfers--lineups and neighborhood pulse--are basically pulse scheduling applied in different situations. A lineup is pulse scheduling used in the evening and in off-peak hours. A neighborhood pulse is pulse scheduling used on only a portion of the system. Most of the operator actions associated with these variants are similar to those for pulse scheduling. The major differences that do exist are pointed out below.

Lineups

Lineups are used by many nonpulse transit properties in the evening or on weekends. The populations served by the sample of lineup properties that participated in this study ranged from 190 000 to 1 800 000, and all but one served more than 500 000 people. Most of these properties use a headway of 1 h for their lineups, which is the same headway often used in the evening by pulse properties.

Given that the term lineup conjures up an image of a row of buses sitting in a line for long stretches of time, it is important to note that most lineups have no more than 5- to 10-min layovers. Again, there may be some adjustments made in routing to accommodate the schedule. For instance, one property reduces some coverage of outlying suburbs, while another adds a "night loop" to some routes. Most of the other actions taken by properties are the same for lineups as for pulse scheduling. In addition, emphasis may be placed on the fact that lineups tend to guarantee that no one gets stranded after the last trip of the day.

Neighborhood Pulse

The difference between neighborhood pulse and full-scale pulse systems is the size of the system in which the pulsing routes are found. With neighborhood pulse, a set of local routes pulse together to facilitate travel within a neighborhood. Because this may occur in areas outside of the congested CBD, neighborhood pulse can be found in very large cities or on any property that has non-CBD subcenters that are logical transfer points. The actions required to do this are quite similar to the actions associated with pulse scheduling.

CONSEQUENCES OF TIMED TRANSFERS

The use of timed transfers does not inevitably lead to any particular set of consequences. Simple timed transfers, pulse scheduling, lineups, and neighborhood pulse clearly all require different levels of effort and generate impacts of different magnitudes. Even within properties that use pulse scheduling, impacts vary greatly depending on the required operator actions. This wide divergence of possible impacts follows directly from the multiplicity of actions that make up timed transfers (described earlier). For the purpose of detailing consequences, these operator actions will be divided into the five categories addressed above: service frequency, routing, schedule adherence, provision of space for buses, and provision of user information. The analysis of each type of consequence--cost, user satisfaction, ridership, and revenue--will focus on those categories of operator actions that have the greatest impact.

Costs

The greatest potential influence of timed transfers on cost arises from changes in bus hours and bus miles that may have to be made to match headways on different routes. In practice, however, it is not clear whether this is an important effect. Frequency changes for simple timed transfers and lineups seem to be small, especially since headways in the evening are often fixed by policy. Frequency changes for pulse scheduling and neighborhood pulse are potentially more significant, but it is impossible to tell in general whether frequencies will be raised, lowered, or both on any particular property. In practice, pulse properties appear to have somewhat longer peak headways and somewhat shorter base headways than comparable nonpulse properties. The operator may feel that, because of reduced transfer time, the peak-period headways can be raised without reducing the overall level of service. Alternatively, the operator may decide to maintain the peak headway to accommodate work riders.

In general, properties that use pulse scheduling do not attribute major cost consequences to frequency changes mandated by the use of timed transfers. Because of site-specific factors, however, it is not possible to anticipate the direction or magnitude of the changes in service frequency needed to implement pulse scheduling in cities that currently do not have it. These impacts must be assessed on the basis of the policies selected by the operators and the preexisting schedule.

The systematic dollar cost differences that do exist between pulse and nonpulse properties stem mainly from extra layover time built into the schedule to ensure schedule reliability. Because timed transfers are based on guaranteeing that buses will meet, more system resources are devoted to this end. As extra layovers are built into the system, two distinct effects can occur. With a greater fraction of vehicle time spent idle, cost as estimated on a per-mile basis will increase because of the decrease in vehicle miles of travel (VMT). Actual total operating costs may decrease because of savings in bus running costs (if no more buses are added). The conflict between these indicators and the small expected size of the impact are compatible with the indecision of many operators concerning the overall cost impacts of pulse scheduling.

Another cost of pulse scheduling that can be significant is the cost for the street space used by the pulsing buses. This cost is not normally a direct financial burden on the operator in the usual sense. However, consumption of street space by the buses can cause an increase in traffic congestion and a reduction in parking-meter revenues as well as aesthetic problems. These costs are not borne by the transit operator but may have to be taken into account in deciding whether to implement pulse scheduling.

User Satisfaction

User satisfaction among transferring passengers almost always increases significantly when any type of timed transfer is used. However, there are several factors that appear to influence the degree of change in user satisfaction, including service reliability, comprehensibility, frequency, and, to a lesser degree, coverage.

Reliability is the key element in determining whether user satisfaction increases sharply with timed transfers. If riders are assured of a very high probability of making their connection, both the mean and the variance of transfer wait time will go down. The variance is especially important because one bad experience can counteract the effects of a large number of good ones. Therefore, operator actions to ensure a high degree of reliability in making connections are essential for a large gain in user satisfaction.

The comprehensibility of the system is a second important determinant of the changes in user satisfaction that accompany timed transfers. If an operator makes riders aware of the timed transfers, then the system is easier to understand and use. Riders who want to transfer need not worry about when the connecting bus will arrive at the transfer point. Schedules are thereby simplified and made less confusing.

Service frequency also affects user satisfaction with timed transfers, although its effect is essentially inverse. Since high frequencies lead to low average transfer wait times, even without timed transfers, the implementation of timed transfers would have a reduced positive effect on user satisfaction. On the other hand, low frequencies mean that timed transfers can have a large positive impact on average transfer wait time and hence on user satisfaction. Simple timed transfers and lineups, which are typically used at times of low bus frequency, are thus more likely to greatly increase user satisfaction. It should be emphasized that this relation to frequency focuses on the change in user satisfaction induced by timed transfers. The overall level of user satisfaction typically would be higher with high service frequencies.

The final factor, coverage, is generally less significant than the first three in determining user satisfaction. It is true that operators often adjust routes to accommodate pulse scheduling or lineups. These changes can affect overall coverage on the outlying portions of routes, the streets used to reach the downtown terminal point in the allocated running time, or the location of the terminal point itself. In practice, pulse scheduling and lineups have had little effect on coverage of outlying areas. However, in at least two cases, changes in the terminal point have affected the level of service available to both transferring and nontransferring passengers. In Brockton, the off-street transfer facility was located several blocks away from the previously used pulse point, which had been closer to the center of town. This led to a net increase in the distances that many people had to walk to gain access to transit. In Lafayette, when the dual-pulse-point system was instituted, people who had formerly traveled on one bus from the west side of town to the CBD were compelled to transfer, which reduced their level of service. In general, though, coverage seems to have been affected in only a minor way.

It is important to consider how changes in user satisfaction affect different groups. Geographically, the four categories of timed transfers inherently have different consequences for different groups of riders. Simple timed transfers only increase user satisfaction for individuals transferring between two particular routes, whereas the effects of neighborhood pulse are restricted to riders in a particular area. Lineups, which are typically used on a systemwide basis, have consequences only for people traveling during off-peak hours. Pulse scheduling will affect the satisfaction of almost all riders; the elderly, the young, and people who transfer frequently will experience the highest gain. On the other hand, riders making peak-hour work trips may have much less of a gain from pulse scheduling because of the heavily radial nature of their trips. For such riders, transfer policy options such as through routing, which eliminates transfers altogether, may be much more beneficial.

Ridership

Simple timed transfers or lineups clearly do not produce large gains in ridership, since the typically long headways on the originating leg remain an important determinant of ridership. On the other hand, some properties have experienced substantial increases in ridership because of the use of pulse scheduling, although many of these properties instituted other service improvements simultaneously with the pulse scheduling. In Brockton, for example, ridership increased sixfold at a time when VMT was increased fourfold to fivefold. Since only 25 percent of passengers now transfer and the reliability of service has drastically improved, a reasonable estimate of the increase in ridership directly attributable to pulse scheduling may be on the order of 10 percent of current ridership. This estimate is substantiated by the experience in Superior, Wisconsin, where ridership rose 10-12 percent with the advent of pulse scheduling and there were no other important changes in service. Furthermore, several pulse operators (including those in Everett, Washington, and Lewiston, Maine) see no definite link between pulse scheduling and ridership.

It is possible to estimate the ridership changes caused by implementation of pulse scheduling. For example, consider a small property where all routes meet at one point, all have unsynchronized headways of 30 min, the overall transfer rate is 20 percent, and the transfer charge is zero. Before pulse scheduling, the average out-of-vehicle time for transferring passengers will be 30 min (15 min transfer time plus an assumed 15 min of initial walk and wait time and final walk time). With pulse scheduling, transfer time will drop to 5 min for a total average out-of-vehicle time of 20 min.

Under this scenario, the increase in ridership attributable to pulse scheduling can be calculated in two different ways. The first way uses the -0.7 elasticity of demand with respect to out-of-vehicle time presented by Domencich (2). Since, with pulse scheduling, out-of-vehicle time for transferees decreases by 33 percent, the number of transferring passengers will increase by 23 percent (0.33 x 0.7). If the initial transfer rate was 20 percent, the overall ridership will increase by 4.6 percent (0.23 x 0.20). This figure does not take into account the change in overall user perception of the system as conducive to reliable transferring. There is a belief shared by several pulse operators that timed transfers at the downtown terminal promote a comprehensible, easily "imaged", and popularly supported system that leads to more riding than simple reductions in waiting time between two connecting lines would suggest.

A second elasticity-based method for predicting the ridership consequences of pulse scheduling uses the pre-Bay Area Rapid Transit aggregate demand elasticity of San Francisco ridership with respect to transfer time (only) of -0.26 calculated by McFadden (3). For the above example, this yields an overall ridership increase of approximately 17 percent (0.67 reduction in transfer time x -0.26). It should be noted that this increase may be equated in the above example to an elasticity of -2.5 for all out-of-vehicle time alone (17/20 percent x 0.33). There is support for bus service elasticities this high under conditions of infrequent service (e.g., comparable to long waits at transfer points--pre-pulse) and relatively high fares (4,5).

Overall, 5-17 percent appears to be a reasonable range for the ridership effects of pulse scheduling. The higher increases would be more likely for systems that increased service reliability at the same time and/or had the potential for significant riding to nondowntown terminal locations because of the presence, at dispersed destinations, of major attractors of discretionary trips or trips by the elderly.

Revenue

The revenue consequences of timed transfers follow directly from ridership consequences as long as the distinctions between groups paying different fares are observed. The key question is whether the revenue gained from increased ridership covers the cost of setting up a reliable pulse-schedule system.

This question can be addressed in a hypothetical case by using the above example. Consider again the small transit property with 30-min headways and without pulse scheduling. To implement pulse scheduling and attract ridership, reliability may have to be increased by adding layover time. Assume this added layover time to be 5 min added to the previous running-plus-layover time of 55 min (two buses on each route).

In this example, assume pulse scheduling is to be implemented at no additional operating cost. Therefore, VMT must be decreased proportionally--that is, by 9 (or 5/55) percent. (In fact, the decrease may be slightly less because layovers decrease mileage-related costs.) Using the typical bus VMT service demand elasticity of -0.7 yields a VMT-related decrease in ridership of 6.3 percent. This decrease in ridership would probably be less because the VMT changes take place at the ends of the routes that are likely to be in low-density areas. In any case, this decrease in ridership from the added layover time is at the low end of the range of the above estimated pulse-schedule-induced ridership increase. Hence, a no-cost implementation of pulse scheduling under this scenario may still attract additional ridership and may be a productive option in this situation. Unfortunately, the actual cost and ridership effects of timed transfers in any real application depend heavily on policies undertaken by the operator to equalize roadways, provide adequate space for all buses to meet, etc. The site-specific nature of all of these factors makes it impossible to generalize results except to say that many operators believe that timed transfers of some sort are the most efficient means available by which to provide improved levels of service under many circumstances.

APPLICABILITY OF TIMED TRANSFERS

Property size is the principal criterion for assessing the applicability of the four different types of timed transfers. Transit properties whose service areas have fewer than 400 000 people are generally able to use pulse scheduling at their main transfer point. On the other hand, larger properties often have lineups but not pulse scheduling. Simple timed transfers can generally be used on any system, although they are more likely to be found on medium-sized properties. This is because small properties usually do not have significant outlying transfer points, whereas large properties have more complex systems for which the scheduling of simple timed transfers at numerous outlying transfer points may not seem worth the effort. Finally, neighborhood pulse is applicable to any system that has subcenters that serve as logical pulse points.

Several other factors, some of which may be related to property size, also affect the general applicability of timed transfers. The first is schedule reliability, which is very important for increasing user satisfaction. A disintegrating-pulse situation, where people cannot be assured of meeting their buses, eliminates the rationale behind a timed transfer system. Hence, cities in which the transit property has problems adhering to schedules would have difficulty using timed transfers in general and pulse scheduling in particular. In addition, on large properties that have severe schedule-adherence problems, increasing user satisfaction by means of timed transfers would tend to be prohibitively expensive. This is one reason why large properties tend not to use pulse scheduling during the day and instead concentrate on times when schedules are more reliable.

Service frequency also influences the applicability of timed transfers. At high enough frequencies (e.g., 15 min), the drop in average transfer time attributable to timed transfers is not significant enough to substantially increase user satisfaction and begin to offset the added costs of timed transfers in city centers (e.g., street space, congestion, etc.). Since larger properties tend to have high service frequencies even during the day, this constrains the applicability of pulse scheduling and possibly neighborhood pulse as well.

Space limitations on the number of buses that can meet at a point also have an important influence on the applicability of timed transfers. The difficulty involved in finding a place in a congested area where all buses can meet explains in part why large properties avoid daytime pulses, resorting instead, in some cases, to lineups in the evening when the CBD is less congested. Moreover, even if there is a place to meet, the distance between buses will have a very significant effect on the transfer time.

Given these size-related reasons why pulse scheduling is implemented only by small properties and lineups are implemented only by large properties, it is appropriate to outline the reasons why the use of pulse scheduling of buses varies among small cities. Clearly, widely dispersed origins and significant numbers of non-CBD destinations indicate that the city is a candidate for pulse scheduling. In addition, geographic layout--the CBD being in the center of the service area, for instance--can make scheduling easier. However, the most influential factor seems to be a political climate in which transit innovation can occur. If political factors determine the level of service allocated to different areas, pulse scheduling may not be feasible. This type of constraint must be addressed on a case-by-case basis. However, if the political climate is conducive to a major change and revamping of service, pulse scheduling has the potential of being a cost-effective way of increasing service and ridership without necessarily increasing operating costs.

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REFERENCES

1. Charles River Associates, Inc. Operator Guidelines for Transfer Policy Design. U.S. Department of Transportation, June 1980.
2. T.A. Domencich, G. Kraft, and J.-P. Valette. Estimation of Urban Passenger Travel Behavior: An Economic Demand Model. HRB, Highway Research Record 238, 1968, pp. 64-78.
3. D. McFadden. The Measurement of Urban Travel Demand. Journal of Public Economics, Vol. 3, 1974.
4. R.L. Carstens and L.H. Csanyi. A Model for Estimating Transit Usage in Cities in Iowa. HRB, Highway Research Record 213, 1968, pp. 42-49.
5. Peat, Marwick, Mitchell, and Company. Public Transportation Fare Policy. U.S. Department of Transportation, May 1977, pp. III.40-III.44.

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Redesigning Urban Transit Systems: A Transit-Center-Based Approach

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Current metropolitan travel patterns in American cities are examined. The inability of highly downtown-focused (radial) transit networks to meet metropolitan travel desires in American cities is described. In addition, the limitations of the grid network approach to route planning are critiqued. A transit network that is designed to converge on a few strategically located transit centers is recommended as having the greatest potential to serve the multidestinational travel demand that characterizes American cities. A planning framework designed to aid planners in the preparation of plans for a transit-center-based transit system is outlined. Its key element is the strategic location of a few transit centers at major activity centers. Regional shopping centers are suggested as ideal sites for transit-center locations. The center-based transit network is assessed critically from operational, financial, and political perspectives. It is concluded that the development of 400-500 transit centers during the 1980s could materially aid the revitalization of transit systems in most American cities.

For the past 20 years or more, most of our large urban areas have been decentralizing rapidly and becoming less dense. As office, industrial, commercial, medical, and entertainment activities have followed suburban population growth to the outer city, a polycentric urban form has evolved that is made up of many concentrations of activities throughout the urban region. As a result, the central business district (CBD) is no longer the single focus of activity in an urban area but has become one among several important activity centers. This evolving land use pattern has produced a regional travel pattern that is much more diverse and less concentrated in a few radial corridors.

Most urban transit systems are still oriented to providing a high level of service to only the downtown in American urban areas. Unfortunately, travel to the downtown typically accounts for less than 10 percent of the total urban travel market in American cities. Consequently, most American urban transit systems are competing directly for, at most, a 10 percent share of the regional travel market and are essentially ignoring the other 90 percent of the market. Clearly, transit's share of the regional travel market cannot be expected to increase significantly (or at all) as long as it continues to focus service only on the CBD while ignoring the several other important destinations in the urban region.

The variety of transit networks that have been operationalized to serve public transportation needs has been very limited. Most transit networks operating in U.S. cities are designed to serve well only the commuter work trip to the CBD. Typically, the routes fan out from the CBD to the suburbs in a radial manner.

The downtown represents the only significant transfer point in such radial networks. This situation is changing somewhat in a few cities with the adoption of the crosstown routing concept, when important cross-radial desire lines are identified and service is designed to meet that demand. But overall, radial networks have been retained over the years by transit operators and planners who still do not believe that a fixed-route service can be designed to serve a variety of regional destinations effectively and economically or that people making non-CBD trips would patronize nonradial service if it were provided.

Given this transit planning perspective, radial systems are extremely limited in serving multidestinational travel. Most riders who desire to reach non-CBD destinations in a radial system are required to travel to the downtown, transfer, and then travel back out again to the final destination. A rider seeking a destination that may be no more than 3 km (2 miles) from his or her origin may be forced to make a 15-km (10-mile), 50-min transit trip. Clearly, this is not a service that is likely to capture a significant share of the non-CBD-bound travel market.

A more recent and relatively uncommon approach to regional transit network design is the grid concept. Rather than focusing service on the CBD, the grid offers north-south, east-west service connections to most regional destinations. The grid network is characterized by two sets of parallel routes spaced at regular intervals, each of which operates along a fairly straight path. Routes are developed as elements of an interdependent, integrated system. In a grid system, a great deal of importance is placed on the transfer. With a single transfer, the rider can reach almost any major destination with little circuitous travel; without the transfer, a rider is severely limited in the number of destinations available. However, it has been demonstrated that, if riders are to be induced to transfer, they must be able to do so quickly and easily, since the grid relies heavily on the transfer. It is therefore critical that efficient, convenient transfers be provided with minimal effort to the rider.

Unfortunately, the financial resources needed to operationalize a regional grid network that permits efficient transfers are so substantial as to make such an areawide system economically infeasible. Thus, the practical applicability of grid systems is limited to those areas of a region that have population, employment, and commercial densities that could support 10- to 15-min, day-long headways.

Whenever possible, a grid network should be developed for those areas that are able to support the level of service necessary to efficiently operate a grid. However, for the remainder of the region, the system must be designed to revolve about a few strategically located destinations if transit is to gain a share of the non-CBD-oriented travel market. The purpose of this paper is to present a framework for planning a transit system that could serve the multidestinational travel needs of people living in suburban areas in an efficient and effective manner. The main thrust of our argument is that the design of a regional transit system should be based on a set of strategically located major activity centers. Each of these locations should be provided with a transit center at which a high level of synchronized service is provided. Each transit center would be the focal point of transit activity for a subregion of the metropolitan area, and patrons would know that almost any destination in the region could be easily reached from any transit center.

Three types of routes would converge at each transit center: local, radial, and circumferential. The local routes would be designed to carry riders from their homes to a nearby transit center.

The radial routes would connect the transit centers directly with the CBD by means of limited-stop, high-frequency service. Circumferential routes would link the suburban transit centers with each other and with other major activity centers.

Like the grid, the routes of such a system would be developed so as to operate as an integrated system. Convenient transfers would be vitally important in such a system, and portions of the service would have to be timed at transit centers to make transfers as easy, quick, and comfortable as possible.

The design of a center-based transit network would be tailored to match the existing regional land use pattern and would have to be carefully developed by the transit operator, planners, and elected officials. Land use patterns and topography vary greatly from region to region, as do regional travel patterns. This makes the specification of design recommendations difficult and forces them to be general in scope. However, some general guidelines have been developed to aid in the preparation of a plan for a polycentric transit network.

This paper outlines and briefly discusses a process for planning and designing a transit network based on a set of strategically located transit centers. Our approach is based on three key points. The first is that every urban region includes several major activity centers that generate substantial amounts of traffic and that, although the CBD may be the largest and most important of such centers, it is no longer the only significant destination in the region. The second point is that fundamental transit-rider behavior can be altered from a "destination" to a "direction" orientation. The basic idea here is that people would rather be moving toward their destination than waiting for long times for nontransfer, and often circuitous, service. The third point is that, given a set of transit centers, a route-schedule plan can be designed that will provide the desired level of service. Getting three types of routes to pulse regularly at a set of transit centers is not an easy task, but it is within the capability of today's planning methods.

Some guidelines for the planning and design of a transit-center-based transit system are presented. These guidelines have been derived from a synthesis of 22 case studies. Table 1 gives the classification of the case in each city (these case studies are available from us as separate documents).

PLANNING AND DESIGNING A CENTER-BASED TRANSIT SYSTEM

Smith (1) has devised a six-step process that can be used to prepare a plan for a transit-center-based system in a large metropolitan region. These six steps are identified below and are then discussed in order:

1. Identify an area or areas where a grid system could be efficiently operated. Generally, this area will be near the CBD and very limited. Identify north-south, east-west corridors to be served by grid routes.
2. Select the number and locations of the transit centers on which the remainder of the system will be based. Use well-known major activity centers whenever possible. Define a primary service area around each transit center identified.
3. Divide the metropolitan area into subregions based on the primary service-area boundaries defined above. Note that the area to be served by a grid network is also a separate subregion. Identify other major activity and employment centers located in each subregion, and classify them as to their regional or subregional importance.
4. Analyze the travel patterns within each subregion and between subregions, by trip type and time, using the best available origin-destination (O-D) data. Determine which travel patterns, in space and time, are appropriate markets for transit service.
5. Design alternative route-schedule plans for those local, radial, and circumferential services judged to be high-potential markets. Evaluate the alternatives and select the plan that best meets the objectives of the various interest groups in the region.
6. Devise an implementation plan that is phased and prioritized.

Figure 1 shows what the results of the first three steps should look like.

Identification of Areas That Could Support a Grid System

Before attempting to delineate a grid service area, the planner must identify a logical set of grid-type streets on which service should be operated. These streets need not form a perfect north-south, east-west pattern but must allow reasonably smooth north-south, east-west bus movement.

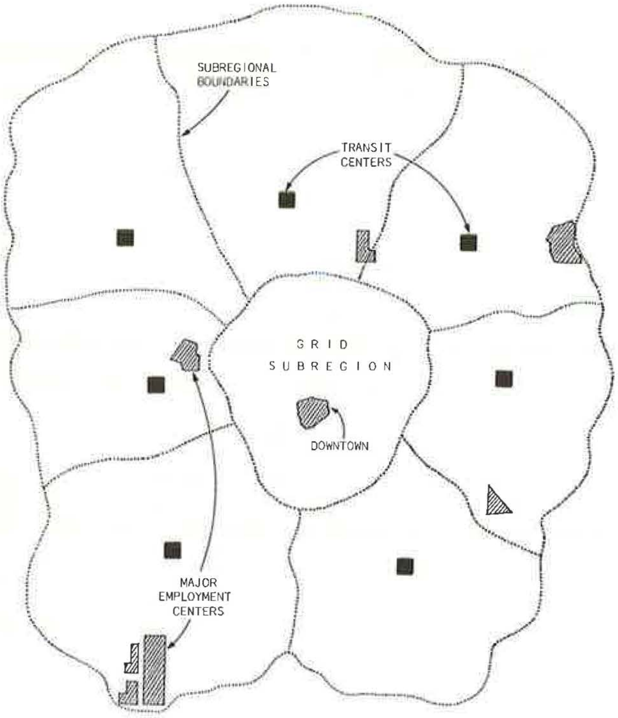
Once the planner is assured that the street system can support a grid system, he or she should define the specific area that could support grid service. The most important requirement is that densities of population, jobs, retail, and other activities be high enough to generate high levels of ridership to a multitude of destinations so that 15-min or shorter headways can be supported. Since such densities will invariably be greatest in the central part of a metropolitan area, the planner should begin with the CBD and work outward, looking for noticeable decreases in these densities.

Generally, the planner will have a good intuitive feel for the dimensions of this area because current rides per capita will typically far exceed the areawide average. Although the densities needed to support a grid system will vary from city to city, it is recommended that the grid service area be

Table 1. Case studies of transit centers.

System Status	Cities with Single Center	Cities with Multiple Centers
Existing and operating	Brockton, Massachusetts; Boulder, Colorado; Bellingham, Washington; Norwalk-Westport, Connecticut; Sacramento, California; Toronto, Ontario, Canada	Portland, Oregon; Nassau County, New York; Edmonton, Alberta, Canada; Vancouver, British Columbia; Hannover, Federal Republic of West Germany; New Delhi, India
Planned	Eugene, Oregon; three Iowa cities	Tacoma and King County, Washington; Santa Clara County, Los Angeles, Orange County, and San Diego, California; Denver, Colorado; London, Ontario, Canada

Figure 1. Results of initial stages of planning process for a center-based transit system.



extended outward from the downtown to those locations at which densities and rides per capita drop off significantly.

Selection of the Number and Locations of Transit Centers

A second important step to be taken in designing a center-based transit network involves selecting the right number and locations of the transit centers around which the route and/or schedule alternatives will be designed. The key to this step lies in locating a logical number of major points that effectively use popular, well-known locations that are strategically placed and properly spaced. By doing this, the planner can serve both destination- and direction-oriented travel, since the same local bus route that is used by some to reach a particular activity center can serve others who wish to use the express service from it to other destinations. It is anticipated that a rider using a particular route to reach the transfer point/activity center for a specific purpose will come to realize the ease with which that route can be used for other purposes and thus be encouraged to use the transit system more extensively.

Ideally, the transit centers should be in locations that (a) generate a good deal of activity throughout the day, (b) are spatially separated in a relatively even manner throughout the region, and (c) are well known and easily remembered. By locating a transit center at a busy location (e.g., a regional shopping center), a reasonably high level of service can be justified. This higher level of service will permit the transit system to serve a broader variety of markets and use the upward spiral concept, which states that, the greater the use of the transit line, the easier it becomes to provide better and cheaper service.

It is also critical that the transit centers be well distributed with respect to the population and employment distributions of the region. Ideally, one transit center should be allocated to every identifiable population cluster or community to minimize the distance between the population and the transfer point. Unfortunately, it is both operationally and financially impractical to have a large number of transit centers if the transfer is to be made efficient. Therefore, it is recommended that only one transit center be located in each subregion that is to be served.

Ideally, a local feeder bus should be able to perform a round trip in a minimum of 30 and a maximum of 60 min. Local routes that require longer travel times will be both difficult to schedule so as to meet simultaneously at the transit center and too long for many to use as a feeder service. Assuming a 19-km/h (12-mile/h) average bus speed and 5 min of layover at either end of the route, these travel times translate into route lengths of 3 and 6.5 km (2 and 4 miles), respectively.

Transit centers should also be located at appropriate distances from each other throughout the urban region. If transit centers are located close together, route overlap, scheduling difficulties, and unnecessary duplication will result. Competition between centers is counterproductive and should be discouraged by locating them at reasonable distances from each other.

Assuming an average speed of 40 km/h (25 miles/h) for buses providing service between transit centers, the maximum route distance between adjacent transit centers should be no greater than 13 km (8 miles). The minimum distance between two transit centers would be 6.5 km (4 miles) if a local service area with a 3-km (2-mile) radius is required.

The transit centers should also be located to maximize their accessibility. Direct access or nearby freeway or major arterial access is often important to the effective scheduling and operation of a transit center. This permits the regional routes to maximize the speeds at which they operate so that faster and more efficient service is provided to regional destinations from a particular transit center. This also allows fast and efficient access for those who wish to reach the transit center by automobile or another transportation mode.

Finally, whenever possible, the transit centers should be located at very well-known and easy-to-find locations in the urban area. A highly visible location will improve the perceived accessibility of the transit center to the user. More important, the locational pattern of the transit centers can be memorized more easily by riders if they can identify them with regional landmarks. Most regional activity centers are fairly well known and visible to the public. However, some (e.g., regional shopping centers) are better than others in this respect. When the locational pattern of a region's transit centers is made easy for riders to identify and memorize, the transit system becomes easier for them to understand and use.

With these locational objectives in mind, the planner should seek to locate a logical set of transit centers. CBDs, whether urban or suburban, can be ideal locations for transit centers, but the planner may experience some difficulties in determining the most appropriate transit-center locations for the remainder of the region. It is recommended that the planner begin seeking non-CBD transit node locations by first identifying and mapping the major shopping centers in the region. Regional shopping centers will generally provide ideal locations for transit centers because they typically satisfy the locational requirements of transit centers very effectively (2,3). For our purposes, regional shopping centers are defined as planned projects that have as a principal tenant at least one department store branch (usually two) with more than 13 500 m^2 (150 000 ft^2) of gross store area. The size of such shopping centers will typically range from 27 000 to >90 000 m^2 (300 000 to >1 000 000 ft^2) of gross leasable area.

Regional shopping centers offer ideal locations for transit centers for the following reasons:

1. A regional shopping center with 27 000 m^2 of gross leasable area will attract, on the average, 13 400 daily person trip ends, and this represents a substantial travel market that transit should seek to share with the automobile.
2. As a result of market forces, regional shopping centers are usually well located with respect to the regional population and other competing facilities.
3. Regional shopping centers are also generally well located with respect to a region's freeway and highway network.
4. Regional shopping centers are visible, well known, and easy to find.

Clearly, there will be instances in which a regional shopping center will not be available or practical to use as a transit focal point. In these cases, other major activity centers should be selected as transit-center sites. There will also be some situations in which two or more shopping centers are located close to each other and neither emerges as the clearly preferred location.

Selection of Subregional Boundaries

Once a set of transit centers has been located, whether at regional shopping centers or at other activity centers, the next step involves the definition of the area around each transit center within which local service should be extended. The resulting transit-center service regions should constitute the subregions on which travel and market analyses will be based.

Subregional boundaries can be determined in a variety of ways. Shopping-center trade-area boundaries, circulation boundaries, and governmental jurisdiction boundaries represent only a few of the possibilities available to the planner. The use of regional shopping centers as transit-center locations suggests that subregional boundary definition begin with an identification of the primary trade area around each designated shopping center. These trade areas typically cover an area with a radius of 6-8 km (4-5 miles), or 15 min of driving time, and are well known to mall managers. Once these trade areas have been identified, it is recommended that their boundaries be adjusted to conform to the following criteria:

1. Boundaries should enclose the entire transit service region.
2. Boundaries should conform as closely as possible to the areal limits associated with 30- to 60-min bus travel times.
3. Boundaries should recognize the region's natural and man-made barriers to travel (e.g., rivers, hills, canyons, and freeways).
4. Ideally, each subregion should contain the following activities and opportunities (listed in order of importance): (a) substantial residential development (25 000-100 000 persons), (b) a regional shopping center, (c) significant employment centers (e.g., office sites, industrial sites, and research parks), (d) health facilities and services, (e) educational centers, and (f) entertainment and recreational opportunities.
5. Land use concentrations, whether residential, industrial, or commercial, should not be divided by boundaries.
6. Boundaries should, when practical, conform to data-collection zones--most important, to census-tract boundaries.

Clearly, subregional boundary definitions will not be able to satisfy all of these criteria all of the time. However, these guidelines should afford the planner helpful direction in defining them. Each region will have to rank the importance of these criteria according to stated land use and transportation planning objectives so that in the case of trade-offs the more important criteria can be represented by the boundaries selected.

Travel-Pattern Analysis and Market Segmentation

Once the metropolitan area has been divided into transit-service subregions, travel patterns within and between the subregions should be examined. The travel-pattern analysis is conceptually simplified, since only two or three types of travel must be examined: travel occurring exclusively within a subregion (local travel), travel going from one subregion to another, and travel from the subregions to the CBD. As an example, Table 2 gives travel volumes between and within subregions in the Minneapolis-St. Paul urban region as observed for 1970 and as forecast for 1990 (4). Clearly, the non-CBD-destined travel volumes are very large and represent a market that transit should try to serve more effectively.

By using O-D data, the planner should segment these three markets into components that it is

Table 2. Travel volumes within and between subregions in the Minneapolis-St. Paul region for 1970 and 1990.

		Home-Based Work Trips		All Other Trips		Total	
Analysis Period	Trip Orientation	Number (000s)	Percent	Number (000s)	Percent	Number (000s)	Percent
1970	To CBDs	192	18	219	6	411	8
	Within subregions	402	37	2415	62	2817	57
	Between subregions	487	45	1265	32	1752	35
	Total	1081		3899		4980	
1990 forecast	To CBDs	230	13	310	4	540	6
	Within subregions	640	36	4100	56	4740	52
	Between subregions	890	51	2930	40	3820	42
	Total	1760		7340		9100	
Change (1970-1990)	To CBDs	+38	-5	+91	-2	+129	-2
	Within subregions	+238	-1	+1685	-6	+1923	-5
	Between subregions	+403	+6	+1665	+8	+2068	+7
	Total	+679		+3441		+4120	

possible to serve with transit. This market-segmentation process is very important. It should define the demand side of the areawide transit planning process and should guide the design of the route and schedule layout at a subsequent stage in the process. Particular attention should be given to defining the time characteristics of these travel patterns, since much of the travel within and between subregions occurs in the off-peak period.

In addition to defining travel desires, the planner should develop a series of descriptive profiles concerning the sociodemographic and land use characteristics of each subregion. These profiles should include but not be limited to (a) population counts and breakdowns by sex and income, (b) population and employment densities, (c) the number of elderly and handicapped persons, (d) the growth potential in various parts of the subregion, (e) employment locations and residential locations of employees, (f) characteristics of automobile ownership and fleet mix, and (g) major arterials and potential transit corridors. Such information should be gathered for each subregion to assist in the preparation of subregional forecasts and to aid in the longer-range route-planning process.

Design of Alternative Route and Schedule Plans

As discussed previously, three types of routes should be laid out that serve and connect the transit centers with all major destinations in the region. The local route structure should be designed to perform a majority of the collection and distribution functions of the system. The structure of these routes must be laid out very carefully if the system is to succeed. It is therefore imperative that these routes be designed to match travel patterns as closely as possible.

The local routes must provide for three basic functions: (a) to operate as a feeder system, carrying riders from their homes to a transit center; (b) to carry riders from their homes to various destinations within the subregion; and (c) to carry transferring riders from the transit center to other destinations in the subregion.

The primary focus of the local route network throughout the day should be on the transit centers of a region. The secondary focus of these routes could change with changes in the travel pattern between peak and off-peak periods. Two sets of fixed routes could ideally be developed to serve peak and off-peak demand separately. During the off-peak period, local routes should be designed to connect spatial concentrations of employees with the transit centers and employment centers identified during the analysis of travel patterns.

The planner should strive to ensure that local routes have peak-hour headways of no more than 20- and 30-min off-peak frequencies. Because the local routes will operate primarily in suburban areas where development density and transit demand will be generally moderate to low, the planner should emphasize good frequencies as opposed to extensive coverage with poorer frequencies. This is based on the assumption that a majority of suburban riders using a local route will be "choice" riders (i.e., riders who have a car or access to one but opt to use transit) who will find good frequency of service more attractive than extensive coverage. This is not meant to imply a system of only a few routes operating at very high frequencies but rather that frequency and coverage levels should be balanced somewhat in favor of good frequencies.

Because headways during off-peak periods are likely to be greater than 15 min, the routes should be timed to meet at the transit centers. It is suggested that the planner begin with a 30-min pulse cycle and 5-min dwell time for the routes at the transit node and then adjust these times if necessary to most appropriately serve local demand. The planner can begin with a 30-min headway cycle as a maximum and effectively shorten it if necessary in terms of even divisors of 60 min (i.e., 10, 15, 20, and 30 min). Such intervals are easily remembered by riders and drivers and should be used for schedule design.

If route lengths are carefully controlled, timed transfers can be effectively achieved. It is highly recommended that no local route operate for a one-way distance greater than 6-8 km (4-5 miles). Any local route that exceeds this distance will have difficulty meeting the schedule of other routes. If the boundaries of a subregion have been properly determined, controlling route length should pose little problem.

It is also recommended that the lengths of local routes be as uniform as possible. It is far easier to schedule a series of routes of approximately equal length to meet simultaneously than a series of routes of differing lengths. This objective may be difficult to achieve because the market within a subregion is not likely to be circular and will, if based on the primary trade area of a shopping center, often be skewed away from the region's CBD. Natural topographic barriers may also pose problems for the planner trying to design a set of routes of roughly equal length that are designed to arrive at a certain point simultaneously. These are problems that will have to be solved separately for each subregion. It may be that some routes simply cannot be efficiently scheduled with the rest of the local network in a subregion without providing substantial layover. In these cases, the planner should not attempt to force that route into a schedule that it cannot maintain. If only one route of a local network cannot be effectively timed, the remaining routes should operate on a timed basis. However, if more than one route experiences problems with adherence to a timed schedule, the planner should consider not using the timed-transfer concept in that region.

Straight, clear routes should be developed to the extent possible to serve local demand. Thelen and others (5) found that no single local routing pattern could be recommended that would effectively serve different areas. Relative costs, coverage areas, and travel times were evaluated for four different hypothetical subregions and four basic local-route designs: narrow-loop routes, wide-loop routes, line routes, and meandering routes. Line routes were found to offer the best travel times but were generally the most expensive to operate. Loop routes were discovered to provide the best subregional coverage but had the poorest travel times. The meandering routes were found to provide a reasonable level of area coverage but had very poor travel times. More important, the narrow-loop and line routes were determined to provide the best connectivity to a transfer point. It is consequently recommended that the planner pursue these route types for providing local route service. However, each configuration clearly involves tradeoffs that will have to be dealt with locally. The decision on which route pattern to use in a given situation should be based on explicit objectives that acknowledge financial constraints and the service needs of the area. Figure 2 shows the hypothetical region used in Figure 1 with a local route design added.

A radial network of trunk routes should be designed to connect the outlying transit nodes with the region's CBD. A limited-stop service should be

Figure 2. Centers and local routes for a center-based transit system.

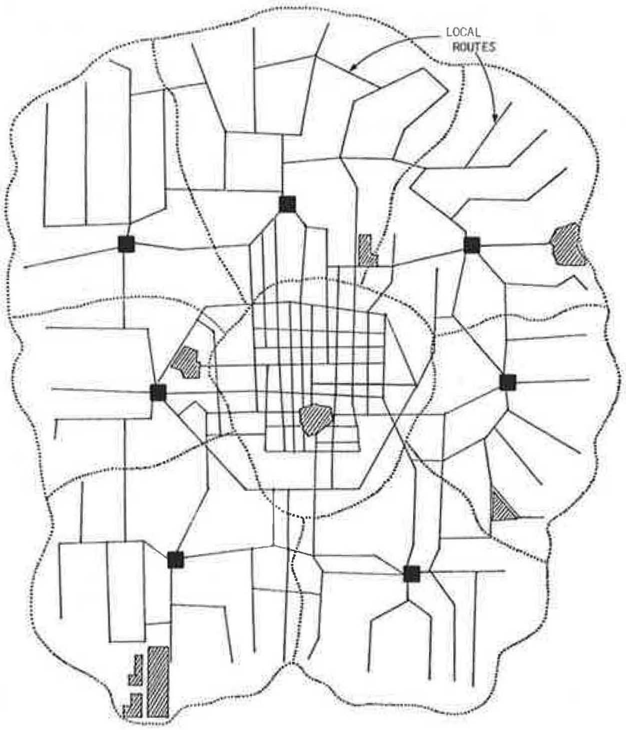
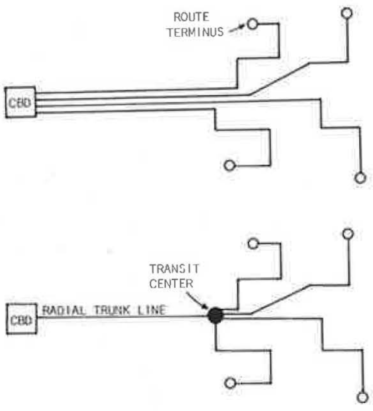


Figure 3. Radial service before and after emplacement of a transit center.



provided on these routes, and headways should be short, especially during peak periods. To the extent possible, these routes should operate on freeways or major arterials to maximize the speeds at which the buses performing this service can operate. Good bus speeds are very important on radial trunk routes. Frequencies should be fairly high. The number of buses required to provide such a high quality of service is overwhelming unless bus speeds are also high.

Trunk routes should be developed by combining several existing CBD-bound radial routes. This will result in fewer radial routes, each with a higher level of service. The number of buses reassigned to such radials will permit a good frequency of service between the transit centers and the CBD. Figure 3 shows the radial-route structure before and after application. The U.S. Department of Transportation (DOT) has conducted studies of this idea, which it calls the "zoned bus concept" (6).

The planner should attempt to design radial trunk routes that emulate the service characteristics of a rail rapid transit line. Good speeds and frequencies probably require that an ambitious program of priority traffic management techniques be formulated to provide the trunk routes with clear, unobstructed paths between the transit centers and the CBD. Special transit-only on and off ramps, special freeway and arterial lanes, and signal preemption may all be needed to allow such a service to be effectively operated.

Circumferential routes should be laid out to connect the various outlying transit centers in the region. The secondary objective of these routes should be to provide peak-period direct service from the transit centers to designated outlying employment centers. For either objective, it is critical that the planner recognize that a large number of the riders on these routes are likely to be choice riders. Circumferential routes should be designed specifically to provide a quality of service that is competitive with the automobile. This can be accomplished primarily by improving the speeds at which the buses providing the service can operate as well as their schedule convenience.

Bus speeds on circumferential routes can be optimized in three ways: (a) by maximizing the express portion of the trip by strictly limiting the number of stops the bus must make, (b) by operating the bus along a freeway for as great a distance as possible between the route's origin and destination, and (c) by using off ramps. It is suggested that the local portion of a circumferential route (i.e., that portion of the route during which stops are made and the bus operates along local streets) generally be no more than 3 km (2 miles) long. While developing a "transit planning framework" for the Denver Regional Transportation District (RTD), R.H. Pratt and Associates found that, if the local portion of an express route was greater than 3 km long, the route's competitiveness with the automobile was greatly diminished, primarily because the average speed of the bus is reduced so much (7).

Circumferential routes can be conveniently scheduled if they are timed to meet with local routes at the transit centers. Because intersuburban transit travel demand is not likely to be great enough to justify and support good frequencies between the transit centers, it is critical that the regional routes be scheduled to meet with the local routes. Because circumferential routes generally cover a greater distance than local routes, they may be difficult to schedule to meet with the local routes. If they are able to operate primarily in an express mode, along freeways or major highways, this scheduling problem can be substantially reduced.

The planner is also likely to encounter problems when structuring a circumferential route schedule to meet with local routes on a timed basis at more than one transit center. This may require the local-route schedules to be adjusted somewhat. It may also be necessary to schedule some layover time for the circumferential routes at the transit center(s) in order for the timed connection to work. Clearly, the planner must develop circumferential and local routes in parallel if timed transfers are to be scheduled effectively.

DOT is currently studying the application of a circumferential routing concept designed to connect the major non-CBD activity centers of a region. This concept has been labeled "beltway transit service" (BTS) and involves an express or limited-stop service that operates for a significant portion of its route over a suburban circumferential freeway or other highway that offers relatively high operating speeds (8).

Two routes will typically provide BTS service, one operating clockwise and the other counterclockwise along the circumferential roadway. These routes will operate in a complete circle, thereby allowing the rider to reach any of the designated activity centers without a transfer. The only stops provided with such a service would be located at the transit centers. The BTS concept has been effectively operationalized in New Delhi, India, where it has served as a key component of a network restructuring that has permitted the transit system to carry 40 percent more riders with only a marginal increase in fleet size.

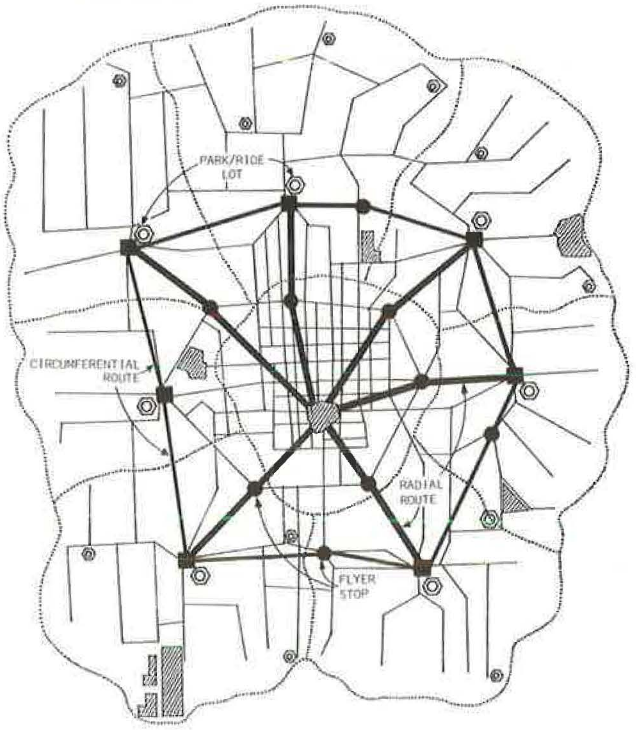
For the BTS concept to be incorporated effectively into a transit-center system, two requirements must be met: (a) A circumferential or suburban high-speed roadway must exist in the region, and (b) the transit centers must be located near the high-speed roadway and its interchanges. The roadway need not follow a complete circle for the BTS concept to be applicable. Any freeway, highway, or combination that provides a reasonably direct line between several transit centers would suffice. The objective is to connect as many transit centers as possible by means of a single bus route without requiring significant route deviation.

Figure 4 shows our hypothetical region with a set of radial and circumferential routes added. Freeway-flyer stops have been located on some radial and circumferential routes. Park-and-ride lots have also been added to show a possible spatial relation between them, the transit centers, and the route structure. In general, park-and-ride facilities should be located adjacent to transit centers and freeway-flyer stops whenever possible.

Implementation Guidelines

The complete restructuring of a transit network in a relatively short period of time is financially infeasible. Meeting the requirements of converting a center-based transit network will require some additional expenses that a transit agency typically will not be able to afford in a short time (e.g., more buses, increased service hours, and, initially, road supervisors).

Figure 4. Fully developed center-based transit system.



It is suggested that the planner organize the implementation process as a market-penetration strategy. This means that the conversion process should be directed first at pursuing those travel markets that are most easily attracted to transit. The rationale for an incremental market-penetration strategy is straightforward. If the transit system appears to be experiencing trouble attracting riders from those markets that should be most easily captured, the entire plan should be reevaluated and adjusted as need be.

The planner might effectively organize a market-penetration strategy as follows. First, the region's major corridors of travel to the CBD that are proposed to be served by trunk routes should be identified. These corridors should then be ranked according to the volume of traffic each carries to the region's CBD. Transit centers should be initially located and built in the highest-volume corridors. For each radial corridor that has been identified for implementation, the local system feeding that corridor must be implemented concurrently. Local feeder systems must be implemented in concert with the trunk lines they serve.

All corridors to be served by radial routes and the affected subregions should be converted before any circumferential service is implemented. In converting to a center-based network, it is most important to establish first the basic network of local feeders to any trunk routes, primarily because these routes will probably carry a majority of the riders in a center-based network and because the CBD work trip, on which these routes should initially focus, is generally the trip most easily attracted to transit.

Once the trunk and feeder routes have been properly implemented, the grid (if desired) and the circumferential routes should be implemented. The travel markets served by these routes are likely to be the most difficult for transit to penetrate; thus, they should be the final series of routes to be implemented. It is recommended that the routes designed to connect the various transit centers of a region be implemented first. If a BTS type of route pattern is being implemented, both clockwise and counterclockwise routes should be implemented together.

Finally, the express services, which are designed to connect the transit centers directly with various regional employment centers, should be implemented. Once again, the order of such service introduction should be in accordance with the transit potential of the market.

At each stage of the implementation process, it is vitally important that the planner develop and use monitoring systems to ensure that prior expectations are being realized. The planner should be careful not to overreact if a particular part of the network is not operating as anticipated. After conversion, a certain amount of time (usually at least six months) will have to pass before trends can be accurately determined, primarily to allow both bus drivers and bus riders some time to become accustomed to the new system. Once a trend that is unfavorable to the operation of the plan has been properly identified, adjustments should be formulated and action taken quickly.

EVALUATION OF THE CENTER-BASED TRANSIT NETWORK

Strengths

Broader Penetration of the Regional Travel Market

In most cases, the CBD-bound work trip would have a higher level of service with a center-based transit system. Travel to non-CBD activity centers would be much easier. Suburban-to-suburban and intrasuburban travel would also be easier and faster. Overall, the higher level of service provided should allow a broader penetration of several markets by transit.

These attributes allow the center-based network to compete better with the automobile for both peak and off-peak travel markets. The ability of the center-based network to provide a good quality of off-peak intersuburban and intrasuburban service that is focused on major activity centers is the key to gaining ridership increases in the future. It is these travel markets that have yet to be penetrated much by transit. Clearly, the rider who uses the center-based system is encouraged to use it as an integrated system of routes, not as a collection of independent, unrelated, and uncoordinated services.

System Efficiency

The center-based network offers very good fleet-optimization possibilities. The suburban-urban bus-load imbalances that characterize radial networks should not prevail in a center-based network. That is, when long bus routes are designed that pass through both urban and suburban sections (as in radial networks), the bus will typically be underused in the suburban portion of the trip, where density and travel demand are lower, and overcrowded during the urban portion of the trip. The feeder buses serving the suburban areas can be designed to most effectively serve that demand, and the radial routes, which operate primarily in areas of greater population and development density, can be adjusted independently of the feeder system to better handle the higher demand. The extent to which such load balances are optimized will be a function of how well located the transit centers are. Conceptually, an optimal location would be one that is at the urban-suburban boundary of a region.

System speed should also improve in a center-based network, since the feeder buses are designed to perform the bulk of rider collection and distribution, thereby freeing the radial and circumferential routes to sometimes operate in limited-stop or express mode. Furthermore, it is often asserted that forcing traffic into channels or corridors will make possible high frequencies with high occupancy ratios. The radial-route portion of the center-based network is designed around this technique and can significantly improve the effective carrying capacity of the system.

As previously noted in this paper, the center-based network permits the transit system to exploit major trip-destination travel markets. Every route will serve a particular major activity center, which will provide a more equal distribution of riders to these centers among the various routes of the system. Off-peak ridership is also encouraged under these circumstances because the non-CBD activity centers on which the network converges are generally off-peak-oriented. These centers will typically offer substantial shopping opportunities and some entertainment, medical, and other services that generate significantly more off-peak than peak travel activity. The ability of the transit centers to handle timed-transfer service will also contribute to better off-peak ridership. Because headways are far shorter during the peak period, the efficiency of the transfer becomes much more important during this time period. Fast and efficient transfers during the off-peak period would encourage more riders to use the transit system. The center-based network thus offers a very good opportunity to reduce the imbalance between peak and off-peak system ridership. A more balanced peak to off-peak system load factor will substantially improve the performance of the bus fleet.

User Comprehension of Network

The amount of information required to use a center-based network extensively is very minimal:

1. Riders do not require schedule information for the radial routes because of the frequency of service. Thus, they can use this portion of the system as they would a rail rapid transit system.
2. To reach the transit center nearest their home, riders can simply use a local bus, since all of the buses provide direct service to the center. Riders would only require schedule information about the local route running nearest their trip origin.
3. The direct services connecting the transit centers permit riders to reach any of these points directly from this origin center. This tremendously simplifies the route information needed, since any bus performing this service will eventually reach all transit centers.
4. Elaborate information displays at each of the transit centers, showing the express routes and the local feeder system serving that center, can be financially justified. Entire system displays would not be necessary, since riders need only information concerning the local system that serves the transit center nearest their destination and the available express service to it. Once at the transit center, riders could determine the best route and departure time, figuring their trip as they go.
5. Because the center-based network relies extensively on timed transfers and the rider is assured that the transfer wait time will be minimal, schedule information concerning connecting routes is unnecessary.

Thus, the only information riders may be required to have to use the system effectively and extensively would be the schedule of the local route carrying them from home to the nearest transit center. Once at the transit center, riders can be assured of a direct and easy-to-identify connection to almost any major regional destination. The locational pattern of the transit centers can be easily memorized by most riders, and the easy recognition of these places provides reassurance that progress is being made toward the desired destination.

System Integration

The center-based concept requires substantial service integration at several locations in the region. It seeks to combine major transfer points with major activity centers and is consequently a framework for integrating a variety of transportation services with the transit system. Since all routes in the network are designed to converge on a series of activity centers, extensive service integration can be accomplished at each activity center/transit center. However, the number of routes serving a transit center will not be so great as to prohibit direct interface between the transit system and other forms of transportation (e.g., paratransit and intercity buses). The objectives of the center-based network and the requirements of service integration appear to be ideally matched, which indicates that this concept has a high potential for service integration.

Weaknesses

Opposition from CBD Interests

Downtowns have traditionally been the focus of transit service in metropolitan areas. The idea of placing transit centers at regional shopping centers involves breaking this tradition and may be opposed by those downtown interests that wish to see the status quo maintained. Actually, the center-based transit concept would increase the quality of service to the CBD, but it will not be easy to convince the downtown interests that such a result would occur.

Capital Requirements

Early evidence suggests that transit centers may cost an average of $0.5 million. If 400-500 such centers were to be built in the nation during the 1980s, as much as $250 million could be required to redesign most of the transit systems in the country. Although this is a small sum in comparison with the cost of even one heavy rail system, it will still not be easy to finance a development program of this scale.

It is also fairly clear that larger bus fleets would be required to operate the schedules required by a center-based transit system. The extent to which this is true is currently unknown.

Public Opposition and Confusion

Change always creates opposition from some quarters, and it should be anticipated that some members of the public will feel that the center-based approach will serve them less well than the existing system. The public should be involved from the beginning in discussions of the concept so that the new design maximizes the use of their knowledge and their desires for service. Such a public participation program will not make public acceptance more likely, but without it a change of the type proposed in this paper is unlikely to be adopted by the transit operator.

Opposition from Shopping-Center Owners and Managers

One should not assume that all shopping-center owners and managers will automatically welcome a transit center on or adjacent to their malls. Many mall people have had bad experiences with buses and the people who ride them and will be wary of proposals to place a bus facility of substantial scale on their property (even if it does not cost them anything). They will have to be convinced that the benefits will be greater than the costs before they are willing to give up any part of their vast parking areas.

Complexities of Schedule Design

The center-based concept will require timed-transfer service in some but not all locations. Designing a schedule that will meet timed-transfer requirements can be a very complex task. The scheduler should have access to advanced computer-based systems to assist in this task. Fortunately, such a system is currently available (9), but it is currently being used by only one transit agency in the country, the Chicago Regional Transit Authority, in the Chicago suburbs. If the center-based concept were to be widely applied, training programs would probably have to be established to help schedulers deal with this problem.

OVERALL ASSESSMENT

The center-based transit system is not a radical concept in that it simply involves using ideas that have evolved and been tested over the years in a somewhat different way. We have attempted to package these ideas in a way that matches better the evolving urban form and travel pattern of the modern metropolis. Changes in urban form have produced changes in travel patterns that are making traditional transit networks obsolete. The prospect is that problems of fuel price and availability will put increasing restraints on the ownership and use of automobiles, an additional factor that suggests that transit should begin to serve those destinations that have traditionally been totally served only by the automobile. We know of no significant indicators that suggest that the urban-form trends experienced in the past two decades will be significantly different in the 1980s and 1990s. The downtown will remain the most important destination for most transit agencies, but the proportion of all destinations that are not located downtown will continue to grow rapidly. If very fuel-efficient automobiles are produced and are purchased by large numbers of Americans in the 1980-2000 period, then any type of transit system will have a much more difficult time being successful. On the other hand, if the price of fuel continues to rise rapidly and a large number of people cannot purchase expensive new fuel-efficient automobiles, then the transit system can be expected to be called on to increase its service to non-CBD destinations throughout the metropolitan area. We judge the latter to be the more likely eventuality. Even in the former case, transit systems will have to be reoriented just to stay even, let alone grow.

This paper has attempted to synthesize and integrate several ideas that are currently being pursued around the country in a piecemeal fashion. In doing so, we have raised many questions that need answers. In our view, a series of simulations needs to be performed in a laboratory environment in order to provide a more detailed technical assessment of the center-based concept presented in this paper. The main question is whether costs would rise much more than revenue. Other technical questions dealing with system scheduling feasibility, fleet requirements, and user comprehension also need to be investigated in more detail. Information regarding political acceptability should also be gathered and analyzed in the near future. Experience is currently being gained in several cities around the country (and in Canada and elsewhere in the world) that will also be helpful in a more detailed assessment of the concept presented in this paper. Case studies of the location, size, and physical design of transit centers have recently been conducted and are available to assist in this continuing assessment.

History has shown that cities are constantly evolving but that public service systems tend to change only infrequently and then in rather massive ways. Perhaps the redesign of urban transit systems is about due for a quantum change as part of the growing trend that may lead to the "reindustrialization" of the country. The problem is the same: a lagging, largely obsolete way of doing things that needs to be updated and rationalized. If we wish to improve the role of transit in providing for the mobility needs of urban areas, center-based transit systems appear to offer a high potential for success.

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REFERENCES

1. S.P. Smith. The Nodal Transit Network: An Evaluation and Planning Framework. Department of Urban Planning, Univ. of Washington, Seattle, master's thesis, June 1980.
2. J.B. Schneider and S.P. Smith. Synchrocentered Transit Systems: The Challenge of the 1980s. Transit Journal, Vol. 6, No. 2, Spring 1980, pp. 39-48.
3. J.B. Schneider and others. Increasing Transit's Share of the Regional Shopping Center Travel Market: An Initial Investigation. Urban Transportation Program, Departments of Civil Engineering and Urban Planning, Univ. of Washington, Seattle, Res. Rept. 79-2, Aug. 1979. NTIS: PB 80-131 360.
4. Metropolitan Plan. Twin Cities Metropolitan Council, Minneapolis-St. Paul, 1978.
5. K.M. Thelen, A. Chatterjee, and F.J. Wegmann. Evaluation of Alternative Transit Routing Configurations in a Hypothetical Low-Density Area. TRB, Transportation Research Record 761, 1980, pp. 53-56.
6. B. Spear and others. Service and Methods Demonstration Program: Annual Report. Urban Mass Transportation Administration, U.S. Department of Transportation, Rept. UMTA-MA-06-0049-79-8, Aug. 1979.
7. A Transit Planning Framework. R.H. Pratt and Associates, Inc., Denver, CO, Jan. 1977.
8. R.H. Winslow and R. Shieldhouse. Beltway Transit Service: Express Bus Service on Circumferential Freeways. Technology Research and Development Corp., Arlington, VA, Sept. 1979.
9. The Transit Network Optimization Program (TNOP). General Motors Transportation Systems Center, Warren, MI, 1980.

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Driver Selection and Training in Human Service Transportation Programs

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In recent years, because of increasing personal transportation costs and a decline in available public transportation, human service agencies have found themselves spending more time and money transporting clients to and from essential human services. As a result, such agencies need increased knowledge about transportation. While agency managers often have a general understanding of basic transportation concepts, they lack an understanding of risk management and the key to a successful risk management program, the drivers. An analysis is presented that is designed to help the various human service agencies to identify (a) the passenger-assistance and driving skills necessary to transport specific program beneficiaries, (b) appropriate screening procedures for selecting drivers, and (c) various programs available to train drivers. Because human service transportation is so specialized, the qualifications and characteristics desired in drivers of human service vehicles differ considerably from those of drivers of other types of vehicles (such as truck drivers). Drivers for human service agencies should have an understanding and tolerant attitude toward others, patience, an agreeable nature, concern for others, and basic first-aid skills.

In recent years, human service agencies have moved into a void in the American transportation system--the provision of transportation services for the disadvantaged who can neither drive themselves nor use existing public transportation. Transportation programs of human service agencies, unlike traditional transportation programs, are mission oriented. Human service transportation programs are designed to provide target groups with adequate medical care, shopping facilities, nutritional services, and recreational facilities, the opportunities for which most people depend on the private automobile or traditional transit.

A recent study done by the University of Tennessee illustrates that a range of human service transportation options is important (1). The need for transportation services in general can be divided into seven distinct user segments:

1. Automobile users--Individuals who have driver's licenses, own automobiles, and can afford to operate their automobiles (although some individuals may require special controls);
2. Conventional public transportation users--Individuals without access to automobiles who are physically able to use public transportation, have conventional public transportation service available, and can afford to use the service;
3. Subsidized public transportation users--Individuals without access to automobiles who are physically able to use public transportation, have public transportation available, but are not able to afford the available service;
4. Expanded public transportation users--Individuals without access to automobiles who could use public transportation service if it were available;
5. Curb-to-curb users--Individuals without access to automobiles who physically cannot use public transportation but could use a service that came to their homes;
6. Door-through-door users--Individuals who are not able to leave their homes without assistance or escort; and
7. Ambulance users--Individuals who need ambulances and their paramedic escorts to take trips of any type.

Unlike public transportation companies (publicly or privately owned) that are in the business of selling the specific type of transportation service they provide, human service agencies are only concerned with obtaining the specific transportation services their target groups need to have access to a wide range of human services. Human service agencies view themselves as advocates for various constituencies. Thus, a human service agency may find itself helping one program beneficiary to obtain retraining to drive a vehicle with hand controls, a second beneficiary to obtain information about available public transportation options, and a third to obtain vouchers that can be used to pay for a ride by taxicab or ambulance.

Where adequate public transportation is not available, the agency must develop options. Options may include the use of volunteers; the use of part-time employees using their own vehicles to transport program beneficiaries; purchase of service from various providers (ranging from churches to school-bus operators to taxi companies to private individuals); reimbursement of family, friends, and neighbors who provide services; and, in some cases, agency-owned and agency-operated vehicles. The type of service offered depends on the special needs of the program beneficiaries (Can they ride in a standard vehicle? What kind of passenger assistance is required?) and the cost of providing the service.

This paper is designed to help the various human service agencies to identify and understand both the driving and passenger-assistance skills that are needed to transport specific program beneficiaries. It also seeks to identify appropriate screening procedures to select those drivers who are most likely to be compatible with the objectives of the agency's program and to identify the various programs available for training drivers to provide the required passenger support services.

There are two major purposes in developing effective driver selection and training programs:

1. Drivers who are not compatible with the objectives of the agency's transportation program seriously reduce the effectiveness of the program and unduly escalate cost.
2. Poorly selected and untrained drivers cause accidents that lead to accidental injury and death to the agency's passengers, which in turn lead to higher insurance rates.

DIFFERENCES IN DRIVER SELECTION AND TRAINING NEEDS

The primary difference in the driver selection and training procedures that should be used is not in the type of agency nor in the way the agency is organized or financed but rather in the mix of driver skills that best serves the agency's customers. This distinction is conceptually shown in Figure 1.

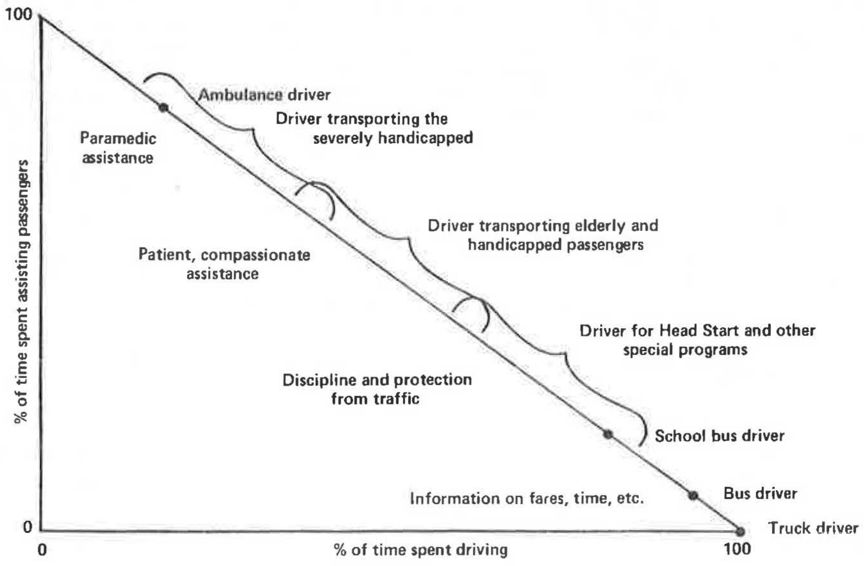
As this conceptual model shows, a truck driver is concerned with driving and has no passenger-assistance duties. A transit bus driver is primarily responsible for driving and is required to give only minimal time to collecting fares, maintaining discipline, providing passenger information on routes and schedules, and, in some cases, physically helping a passenger. A school-bus driver, on the other hand, must spend more time assisting the passengers, since discipline is more of a problem with children and the children must be protected when traveling to or from the bus, especially across a busy street. An ambulance driver is required to be well trained in paramedic and first-aid skills, since the primary purpose of the ambulance service is emergency medical service in conjunction with transportation.

Drivers for various human service programs have responsibilities that range between those of the paramedic and those of the school-bus driver. The duties and skills of a driver transporting Head Start children or operating a church bus to a local Sunday school are much like those of the typical school-bus operator. On the other hand, a program that transports the severely handicapped, the elderly, or autistic children may require that the driver spend almost as much time in passenger-support duties as the ambulance driver.

Thus, it is important that the human service agency realize that "driver" is not a generic term that applies to the full range of driving and passenger-assistance responsibilities. The potential responsibilities of human-service-agency drivers include skills in the following categories: general driving, accident avoidance, passenger assistance, human relations, emergency first aid, nonmedical emergency, and basic transportation operation.

If being a driver were a generic responsibility, then the many truck-driving schools could be used to train ambulance drivers, human service drivers, bus

Figure 1. Sliding scale of driving-nondriving duties.



drivers, and truck drivers. If "passenger assistance" were a generic skill, then the American Red Cross, which teaches first aid and paramedic skills, could be used to train school-bus drivers and transit operators.

In some programs (ambulance services and services to the severely handicapped), the passenger assistance that must be rendered is primarily an immediate professional medical response. On the other hand, passengers who are frail, have limited mobility, or have poor hearing or sight need patient understanding and gentle assistance, including constant verbal reassurance. Young schoolchildren and children in Head Start need an entirely different type of assistance. Each of these different types of passenger assistance requires a different personality type, a different skill, and different training.

IMPORTANCE OF DRIVER SELECTION AND TRAINING

Motor-vehicle transportation is subject to accidents, and the cost of these accidents is great, not only for the individuals involved but also for society. During 1977, there was an accident for every 5.4 registered vehicles. One out of every 4444 persons died, and 1 out of every 39 persons was injured in a traffic accident.

The cost of accidents is very large. Costs arising from property damage, legal fees, medical and hospital bills, funeral bills, loss of income during convalescence, and the administrative cost of insurance were almost $48 billion, or $332.45 for every registered vehicle on the highway. As a consequence, accident costs are a large part of the cost of operating a vehicle, in many cases exceeding fuel cost. Driver error accounts for 90 percent of all accidents.

Although all drivers will probably be involved in an accident sometime, some drivers are chronically involved in accidents. The Survey Research Center of the University of Michigan states that 6 percent of drivers are involved in 45 percent of all traffic accidents (2).

Many researchers believe that people "drive the way they live" (3). Individuals with emotional, psychological, depressive, suicidal, highly aggressive, or antisocial tendencies and negative or rebellious attitudes tend to drive the way they live and are frequently high-risk drivers. People who do not adhere to general societal rules probably will not adhere to general traffic rules.

Driver-training programs are only as effective as the motivation of the person to be trained. Students from high-school driver-training programs, who view the training as a necessary hurdle to getting a license, receive very little benefit from driver training, whereas drivers in the 35-55 age group who take the National Safety Council defensive driving course can reduce their accident involvement by as much as 50 percent (4).

The key to a good transportation program is to select individuals who live safely and drive safely and who identify with the mission of the agency. These individuals can then be effectively trained to provide human service transportation and to provide it safely.

A human service transportation program is only as good as its driver selection procedures and the subsequent training of the drivers it selects. The selection process should involve a thorough examination of each applicant to document the applicant's qualifications.

Traits, rather than demographic classifications, should be used during the screening process. The following traits should be considered in examining each applicant:

1. Four or more years of driving experience;
2. Absence of alcohol and/or drug abuse;
3. Good physical condition (applicants should not be subject to chronic conditions that might cause a sudden loss of control--such as epilepsy, diabetes, and heart problems--and functional rather than chronological age should be used);
4. Good driving record with few violations and accidents (no more than one accident or violation in the preceding three years, which should be weighed by driving exposure);
5. Predictable job history (frequent, unexplained job changes have been associated with poor driving performance); and
6. A willingness to absorb training, accept directions, and identify with the mission of the agency.

Depending on the target groups transported, the following traits should be considered: (a) patience with children; (b) emotional stability; (c) an understanding and tolerant attitude toward others, especially older or handicapped individuals; (d) independence and responsibility; (e) agreeable rather than aggressive nature; (f) safety consciousness; (g) reality orientation; and (h) ability to accept blame and to recognize personal limitations. These characteristics provide agencies with a guide to driver selection that allows flexibility; it must be emphasized, however, that management's responsibility is to select the best-qualified candidate if accidents are to be minimized.

TASK ANALYSIS

Driver is not a generic term, especially when a large part of the driver's responsibility is rendering assistance to passengers. Therefore, the human service agency must be able to define what is expected of the driver before detailed selection criteria can be established and before the required training can be prescribed.

The tasks that a human service driver may be expected to perform can be grouped in the seven general skill areas mentioned earlier. These skill areas can be described as follows:

1. General driving skills allow the driver to control the vehicle adequately.
2. Accident avoidance skills help the driver to avoid dangerous situations created by other drivers.
3. Passenger-assistance skills can be used to assist handicapped individuals in getting to the vehicle as well as in boarding it. Securing passengers in the vehicle is also a very important consideration.
4. Human relations skills help the driver to maintain discipline, control the driver-passenger relationship, and instill confidence in the passengers.
5. Emergency first-aid skills help the driver to respond to medical emergencies such as falls, accidents, heart attacks, or epileptic spells.
6. Nonmedical emergency skills involve developing contingency plans for protecting passengers in case of occurrences such as vehicle breakdowns and flat tires.
7. Basic transportation operation skills help the driver understand the cost of operating vehicles and steps that can be taken to control cost.

It is recommended that all drivers be proficient in general driving skills and have specific skills required by local conditions. In addition to controlling their own vehicles, drivers must be able to predict what other drivers will do and to avoid accident-causing circumstances created by other drivers. Since a major reason for providing human service transportation is that the passengers cannot use existing vehicles and services, drivers of human service vehicles must be able to assist passengers. Drivers must have passenger-assistance skills to operate special equipment that may be needed by handicapped individuals. It is also recommended that drivers understand the characteristics of human relations in dealing with passengers. If an accident should happen, drivers must be able to administer a minimum level of first aid to save lives. Nonmedical emergencies often arise, and drivers should have a well-understood plan to protect the passenger from injury after the vehicle becomes disabled. Finally, the drivers must be able to recognize and avoid costly or dangerous transportation practices to keep agency costs and passenger injuries to a minimum.

Drivers are the agency's field force. They can be involved in identifying problems, managing vehicles, making suggestions, and promoting safety programs. Drivers are the individuals who create the situations in which liability is incurred. The safety and attitude of the passenger and the public are largely determined by drivers. It does not matter if drivers are agency employees driving agency vehicles, volunteers driving agency vehicles, staff members using their own vehicles, part-time employees using their own vehicles, volunteers, or contractors--the situation is virtually identical, and similar training is needed. Part-time employees or volunteers who live near the passengers or who are known by the passengers may know the special needs of the clients and may be able to avoid some of the problems that may occur when passengers are driven by a complete stranger.

DRIVER SELECTION

A good driver selection program is based on an exact description of the job, minimum criteria that a candidate must possess to perform the job, and the personal traits that make an excellent employee so that, when two applicants both meet minimum requirements, there will be a basis for selection.

Driver Tasks

The first step in driver selection is to identify those specific tasks that apply to the agency. Does the agency transport individuals who are blind, those who need door-through-door service while sitting in a wheelchair, or young children with discipline problems? Does the agency operate in rural areas, in severe cold weather, or on toll roads? The skills that are essential to the agency must be identified. The primary duty of the human-service-agency driver may be to assist program beneficiaries whether they need assistance with a wheelchair, help into the vehicle, help in fastening their safety belts, help in locating a drug store, help into the hospital, first aid, or help in scheduling their next appointment. The driving duties simply complement the primary responsibility.

Some systems have two individuals--an escort and a driver. Even in these systems, the driver performs the duties of an escort first and of a driver second. Many drivers have difficulty bridging the gap from professional driver to professional escort, since entirely different skills are required. Thus, the first step in an effective driver selection program is to define what the driver is expected to do.

Minimum Job Requirements

Once the agency has determined exactly what is expected of the driver, it should determine the minimum requirement for a person to be able to perform the job. The basic questions are the following:

1. Is the applicant physically, mentally, and emotionally able to perform the job?
2. Does the applicant identify with the mission of the agency and indicate a desire to work with the type of program beneficiaries that the agency transports?
3. Does the applicant exhibit proven driving skills and a safe driving record?
4. Does the evidence show that the applicant can be trained to the degree required?
5. Does the applicant show the degree of emotional maturity and self-control necessary for the job?

Minimum standards must be set for each of these areas.

The agency will need several items to screen drivers. An application form is used to identify physical problems, to determine prior driving experience, to obtain the driver's license number for the motor-vehicle check, to determine experience in volunteer and other human service activities, and to locate references that can be contacted to determine the driver's emotional maturity. A form for requesting motor-vehicle records is used to obtain a copy of the applicant's driving record. A physical examination should be performed by a licensed physician, who should be thoroughly familiar with the driver requirements. The examination should identify those physical conditions that could cause the driver to lose control of the vehicle or could lead to on-the-job injuries. Each agency will want to develop a checklist to make sure each area is covered.

There are several factors that affect the agency's driver selection strategy:

1. The agency should review the task analysis and should identify those applicants who possess the minimum skills and traits necessary to effectively transport the beneficiaries of the agency's program.
2. The agency should determine its ability to attract drivers. The agency should not be too quick to discount the fact that "psychic income" is the real attraction of the job, especially in the case of volunteers. Thus, the payment scale should emphasize both dollar income and psychic income. This emphasis may strongly influence the potential driver pool (especially volunteer and part-time employees) available to the agency.
3. The agency should consider which employees are most likely to be reliable. High absenteeism rates create a need for expensive backup employees. High turnover rates are a major concern of an insuror, since a high turnover rate generally indicates poor employee morale. High turnover generally leads to poor driver selection and training, since much time is spent screening and training drivers who work only a few days. Mature individuals who know the community, who desire to help their friends and the community, and who are not looking for a new, glamorous career are probably the most desirable driver candidates. Special consideration may be given to individuals who are not totally dependent on their income for support, such as retired military employees, off-duty firemen and policemen, farmers between crop seasons, housewives who are looking for employment while the children are in school, and students looking for employment while attending school.

4. The agency should consider the needs of its beneficiaries and determine the potential for ridesharing and timesharing. In many cases, program beneficiaries who can use standardized vehicles can be transported by existing providers such as other agencies, taxicabs, commuters driving their own vehicles to work, and intercity or transit buses. If the program beneficiaries need trips only during limited periods of the day, the agency should look toward timesharing (hiring part-time drivers and/or off-duty firemen and policemen or others who use their own vehicles) to provide service during that period.

5. The agency should categorize the program beneficiaries by the type of transportation needed. If passengers who require special assistance are consolidated in a single category, the remaining passengers can be transported with substantially less sophisticated equipment and driver training.

6. The agency should decide which services can be provided better by existing volunteer, contractor, and nonprofit agency programs that also supply transportation.

7. The agency should decide the degree to which it can employ the handicapped. This requires a special evaluation of the person's disability in light of the tasks outlined in the task analysis. Severely handicapped individuals may be excellent drivers of specially equipped vehicles if passengers do not need assistance. In other cases, handicapped individuals must be able to drive the vehicle, to assist passengers who have special needs, and to evacuate a vehicle in case of accident or emergency. No general rules should exclude the handicapped from applying for full- or part-time positions, but in no case should the agency use drivers who are subject to uncontrolled epilepsy, heart attacks, high blood pressure, uncontrollable diabetes, or other conditions that can cause sudden loss of vehicle control or that severely affect their ability to use judgment in operating the vehicle. Passenger safety is paramount.

8. The agency should not reject the use of low-income or minority employees, nor should it employ individuals simply because they belong to a disadvantaged group or are available at low or no cost to the agency (e.g., Comprehensive Employment and Training Act employees). Each disadvantaged employee should be screened just as any other employee is screened.

Categorizing Applicants

After considering all these factors, the manager can group applicants into three groups. The hirable individual will have the required physical, mental, and attitudinal characteristics needed for the job and will have mastered most or all of the skills and attitudes that are taught in the training program. Such an individual is a desirable employee but might cost the program more than the agency can afford to pay.

The trainable candidate possesses the requisite physical, mental, and attitudinal characteristics but requires training in skills needed to perform the transportation and passenger-assistance tasks conducted by the agency. A number of job skills, such as passenger assistance or first aid, can be taught. On the other hand, behavior traits, such as identification with the agency mission and adherence to good driving practices, are difficult to develop by training.

The potentially trainable candidate would be expected to have the requisite physical and mental abilities. However, this individual would differ from the first two types in that inappropriate social characteristics may have been learned along with habits leading to a poor driving record. Employing this type of candidate requires an extra step--diagnosing the cause of the poor driving record.

Unless the agency has a manager familiar with job-enrichment programs, the success of the potentially trainable driver may be quite low and use of such drivers could result in high insurance rates and accidental death and injury to clients. If the agency has a highly motivated manager who can help potentially trainable drivers experience something that helps them identify with the mission and purpose of the agency, the success of the potentially trainable driver may be improved substantially.

Legal Considerations

In an era of nondiscrimination and affirmative action programs, many program managers are concerned about their ability to screen out undesirable drivers if the applicant happens to belong to a group that traditionally has been discriminated against. The central question lies in the balance between meeting quotas and selecting safe drivers. Laws have been passed that prohibit discrimination on the basis of age, sex, or race. Although age and sex may be used as bona fide occupational qualifications, the courts have been reluctant to support either of these unless a strong argument can be mounted that all members of the excluded group could not perform the duties of the job safely and efficiently. This does not mean, however, that these individuals should not meet the same basic physical, driving, and mission-identification standards as other drivers.

DRIVER TRAINING

Once a qualified driver has been selected, the agency must instill professionalism and provide adequate training so that the driver fully understands what is expected and knows how to do it.

Professionalism

An important ingredient of the training process is the motivation of the employee. If driving the vehicle is simply a job and the driver is simply "putting in hours", then the training will probably not be effective. Human service professionalism consists of both the driver's motivation for helping the agency accomplish its mission and the driver's willingness to accept responsibility for preventing accidents. Candidate motivation is a key element in the driver selection process. This innate motivation must be cultivated and augmented by the manager of the human service agency to help the new drivers identify with the needs of the program's beneficiaries and recognize the importance of the agency's mission.

The second step, getting the driver to accept responsibility for accidents, is accomplished by continual training and an understanding by both the driver and the manager of the definition of an "avoidable" accident. The driver is professional when he or she fully realizes that an accident can cause physical injury or accidental death to a passenger and that the driver is the individual who determines not only whether the agency's mission is accomplished but also whether the mission is accomplished without injury to the clients. The importance of the driver's role is reinforced when the driver feels that the most professional training available is being given. With this training, the driver is expected, as a professional, to see that transportation is provided safely, that passengers are assisted effectively, that vehicles are maintained adequately, and that all preventable accidents are avoided.

In-House Versus Professional Training

One of the fundamental questions that an agency must address is whether to provide training by using in-house personnel or using professional teachers in a formal program. There is a tendency for many agencies to try to conserve funds by using existing staff to train drivers. This approach is appealing from several points of view. It conceals the true cost of training, since the cost is in the form of reduced productivity, driver salaries, and administrative salaries instead of indirect training expense, and it makes the agency feel self-sufficient in that it feels that it is able to train drivers anytime it desires.

There are, however, several problems with in-house training. Training invariably takes a back seat to the primary responsibilities of the in-house personnel conducting the training. Responsibility for training is often delegated to someone who may intuitively do an effective job of driving but may not know why or how to teach someone else. Drivers do not sense the importance of training when it is done in a haphazard fashion. In-house training is often very informal, and there is no assurance that all areas will be covered, since a formal outline is seldom followed.

Ironically, professional training often offers many advantages, including lower cost and greater flexibility. It is often less expensive to hire professional trainers than to prepare existing employees to be teachers or trainers.

Agencies usually are not large enough to offer regular training sessions for new drivers unless they combine their efforts with those of other agencies. Thus, the cost of one-to-one in-house training becomes very expensive. (The salary of the trainer is usually greater than the cost of the professional training where the professional training is done in groups.)

Insurance companies are familiar with known training programs, but in-house efforts are of unknown quality, and thus there is uncertainty about the quality of the training in the mind of the underwriter.

Goldstein (5), in quoting a study by Lefkourtz, suggests that the best method would be to integrate off-site training, using simulation, with on-site, follow-up training by the manager when the employee returned to work. This follow-up focuses on interaction between the employee and the supervisor (and possibly other employees) to discuss the training experience and the ways in which the training specifically relates to the employee's job situation. This reinforces the off-site professional training, allows the driver to transfer the learning to the actual job situation, and bonds the driver to the employer with a sense of pride, professionalism, and identification with the mission of the agency. This dual approach would allow the best training for employees: professional, off-site, planned instruction followed by an on-the-job, follow-up phase. Each type of training would be doing what it can do best, and the agency would discover the most cost-effective way to train its employees.

ADMINISTERING A DRIVER SELECTION AND TRAINING PROGRAM

The manager of the human service agency has many transportation options. Although these different options allow the selection of cost-effective alternatives, they also require increased managerial attention, since a slightly different management approach must be used to administer each option.

Some of the options available to the manager of an agency that provides human service transportation include referrals to other providers, use of the agency's fleet, use of privately owned vehicles, and contracting. Other available transportation providers may include transit, taxicabs, intercity bus lines, airlines, other human service agencies, charitable organizations, volunteer programs, and consolidated transportation programs. The agency's fleet may be driven by full-time or part-time drivers, volunteers, or agency staff (whose primary duties are other than transportation). Privately owned vehicles used for transportation services may be owned by agency staff, part-time agency employees, volunteers, or friends, family, or neighbors of agency clients. Vans used by private-sector commuter vanpool programs may be loaned during noncommuting hours.

Several contracting options are available to the agency. Contracts may be signed for a specific trip, a specific program beneficiary, a specific route, an on-call service, part of the seats on a vehicle already making the trip (ridesharing), or all services needed by the agency. User-side subsidy programs, voucher programs, and block purchase of tickets are also options.

In considering each of these options, the agency manager must consider two questions: What special skills and training are actually needed to transport program beneficiaries safely? To what degree can the agency determine driver selection criteria and influence the drivers to be trained?

The first question is one that the agency can answer directly. The agency can determine both the typical needs of program beneficiaries and the special needs of individual clients. The answer to the second question is determined by the degree of influence that the agency has over the driver. If the agency desires to transport a program beneficiary by transit bus or airline, the agency will have little or no influence over the training of the driver. On the other hand, if the agency contracts with another organization (public, nonprofit, or contractor) to provide transportation in a specific geographic area for a six-month period of time, the manager will be able to specify the degree of training required. If the driver is a full- or part-time employee, the agency is not only expected to set standards but is also legally responsible for the correctness of the standards, especially if the agency owns the vehicle. Volunteers, family, friends, and neighbors of the passenger can also be trained, but this is done through motivation and appealing to the desire of the drivers to better serve the persons whom they have a commitment to serve. Thus, each management option requires a slightly different management approach. However, proper driver selection and training will be an important component in each case.

REFERENCES

1. T.C. Hood, L. Bell, and K.W. Heathington. Planning for the Transportation Disadvantaged: A Classification of User Groups. Transportation Center, Univ. of Tennessee, Knoxville, 1978.
2. University of Michigan. Public Attitudes Toward Auto Insurance. U.S. Government Printing Office, 1970.
3. D. Shinar. Psychology on the Road: The Human Factor in Traffic Safety. Wiley, New York, 1978.
4. T. Planek and others. An Evaluation of the National Safety Council's Defensive Driving Course

in Various States. Accident Analysis and Prevention, Vol. 6, Dec. 1974, pp. 271-297.
5. I. Goldstein. Training Program Development and Evaluation. Behavioral Science in Industry, Series II, Brooks/Cole Publishing Co., Monterey, CA, 1974.

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