EFFECTIVENESS OF ALTERNATIVE DOWNTOWN AREA BUS DISTRIBUTION SYSTEMS

Alf R. Eriksen, Norconsult A. S., Bergen, Norway; and
Edward A. Beimborn, Systems-Design Department,
University of Wisconsin—Milwaukee

An analysis is made of alternative bus transit distribution systems in central or downtown areas. This is done through the use of a model that simulates the operation of buses as they travel through a downtown area, stopping at signalized intersections and at designated stations to take on passengers. Variables such as bus headways, passenger arrival rates, and passenger boarding times are treated stochastically in the event-advanced simulation. A total of 20 alternatives were tested with the simulation. The alternatives included preferential bus treatments, such as exclusive streets for buses, grade-separated busways, and bus-actuated signals, and facility improvements in the form of skip-stop operations, bus loading bays at stations, and improved boarding and fare-collection methods. The results indicate that transit operations in central areas can be substantially improved by the use of preferential bus treatments and facility improvements. Reductions of bus operating times to less than half of those of conventional operations were found.

•IN RECENT years, the U.S. Department of Transportation has placed major emphasis on the movement of people, rather than vehicles, on urban freeways and streets. Policies have been developed to encourage the use of buses in preference to individual automobiles. This, of course, is particularly desirable in urban areas, where the competition for street space is high and where congestion is part of the everyday scene. Some typical forms of preferential bus treatments include exclusive bus roadways, exclusive bus lanes, and bus-actuated traffic signals. These enable buses to bypass areas of traffic congestion and thereby reduce travel times.

Exclusive lanes or streets for buses should carry traffic volumes comparable with other lanes and streets to demonstrate sufficient utilization of such facilities within a short period of time after implementation. If not, the demand for private driver use of the exclusive bus lanes and streets will mount, and decision-makers eventually will have to yield to public demand. This would, of course, jeopardize some of the very basic goals of express-bus mass transit—namely, reducing travel times and encouraging drivers to leave their cars at home.

In addition to making mass transit more attractive by increasing the operating speed, reduced travel times also increase the economic efficiency of transit operation. A reduction in delays would make the transit driver more productive, and the number of transit vehicles could be reduced without any loss in level of service.

This paper describes the development of a technique for evaluating the efficiency of alternative mass transit distribution systems and quantifying the time savings that can be expected from the installation of preferential bus treatments and bus facility improvements in central areas. A major portion of the research involved the structuring of a computer model that simulates the flow of buses through a central area and then using the model to test the efficiency of alternative improvements on a specific case study. The model was used to evaluate alternatives and select viable treatments for

---

Publication of this paper sponsored by Committee on Busways and Bus Lanes.

improving central area transit operations. This information indicates to the transportation planner what improvements would be needed in order to maintain an adequate level of service and what changes might be considered necessary to meet future demands.

MODEL FORMULATION

In formulating the model, the primary objective was to provide a realistic representation of the operational behavior of buses as they travel through a central area during the peak hour. In order to simulate the alternative systems, it was necessary to identify the components of a central area bus distribution system (as discussed later) and to make basic assumptions about their operating characteristics based on historical and observed data. Stochastic variables such as bus headways, pedestrian arrival rates, and passenger boarding times were also required and were generated randomly according to appropriate statistical distributions.

A flow chart of the model is shown in Figure 1. The simulation, which is event-advanced, computes and reports the delays and travel times as the vehicles pass through a downtown area, stopping at signalized intersections and stations as determined by the input characteristics of the alternative system to be tested. The model proceeds through the simulation of a bus arriving at an intersection and performing all necessary operations for the next block of the route. These operations may include stopping for a signal, stopping to board passengers, and waiting in a queue behind other buses. The bus then moves to the next intersection and through the route until all operations are performed. The next bus then proceeds through the route, and the simulation proceeds until all buses have passed through the route.

By changing the variables representing the performance characteristics of the various components of the system, the model is able to compare alternatives and to indicate the consequences that can be expected from various facility improvements. The simulation program is flexible enough to accommodate any alternative presently under consideration, along with any alternative that might be included at a later date. Because it was impossible to predict exactly which alternatives would be explored in the near future, it was essential that flexibility and provision for rapid, simple modifications be built into the model.

The model was constructed in a 2-phase procedure. The initial phase produced a general model to test the more basic assumptions that were made about the systems and to verify that the model recognized all travel times and delays and assigned buses and passengers to their proper destinations. The second phase of the model building comprised the development of the submodels containing stochastic representations used during the simulation runs and the inclusion of these into the general model. The end product was a simulation model capable of testing a broad range of alternative distribution systems in a reasonably realistic manner. Further details on the nature of the model can be found elsewhere (1).

DEVELOPMENT OF ALTERNATIVES

Definition of System Components and Options

In order to simulate the flow of transit vehicles during a peak hour in a central city area, it is necessary to identify the various common components of each of the alternative systems. For each of the system components, such as the right-of-way on which the vehicles run, there are 2 or more possible options that could be used, such as exclusive lanes, exclusive streets, or exclusive right-of-way on elevated roadways. Each system component has a certain characteristic associated with a specific option for that given component; for example, for the busway component, a certain speed would be associated with buses running on an exclusive street whereas a different speed would be typical for an elevated system. The characteristics associated with each of the options that can be exercised have been identified and given quantitative values based on field observations in Milwaukee and Chicago and on historical data. These values then represent the input variables of the model. In this model a central area transit system consists of 7 components, each of which has 2 or more options. By combining the 7 components into a transit system and in turn changing the options for each system component, a series of alternative systems can be developed. The model then simulates the operation of each system. From the results of the simulation, the alternatives can be evaluated for efficiency and time saving. The 7 system components and the possible options for each of them are listed in the following, grouped under three types—roadway components, station components, and vehicle components:

Roadway Components

1. Busway—This constitutes the roadbed, street, or structure on which the buses run; the right-of-way contains the following options: (a) buses operating in mixed traffic; (b) buses operating on exclusive lanes or streets and with at-grade intersections with other streets; (c) buses operating on grades separated by exclusive systems, such as subway or elevated busway.

2. Traffic signals—Where the buses operate at grade, traffic signals are major contributors to bus delays: (a) fixed-cycle signals; (b) bus-actuated signals; (c) no signals.

Station Components

3. Station layout—The station layout determines whether the buses stop in the through lane or in special bus bays: (a) bus stops in through lane; (b) bus stops in bus bay.

4. Station spacing and stopping configuration—Vehicles can have a number of options involving where and how often they stop: (a) all buses stop once every third block; (b) skip stop with 1 station every 2 blocks; (c) skip stop with 1 station every 3 blocks; (d) skip stop with 2 stations every 3 blocks.

Vehicle Components

5. Bus boarding—With the assumption that a bus has 2 doors, the question is how they can be used more efficiently during the peak hour when the passenger flow is basically one-directional: (a) one door for entry and one for exit; (b) mixed entry and exit at both doors.

6. Fare collection—Several alternatives can be tested to find a feasible solution corresponding to various levels of service: (a) exact fare paid when boarding; (b) no fare collection when boarding, but collected at the station, prepaid passes, pay as you leave, etc.

7. Vehicle size—With the likelihood of mini-buses it was felt that more than one vehicle size should be tested: (a) large bus (seat capacity = 50); (b) small bus (seat capacity = 30).

Combinations of all of the possible alternatives will give several hundred systems. It is neither feasible nor necessary to simulate such a number of alternatives to arrive at meaningful results. By looking at the various options mentioned under each system component, it was evident that several options will have identical operating characteristics for the purpose of simulation. To arrive at a reasonable number of systems reflecting a broad range of alternatives, certain combinations and eliminations of options were made, resulting in a set of 20 alternatives. The first 4 alternatives involve buses operating in mixed traffic, alternatives 5 to 13 involve buses operating on exclusive streets, and alternatives 14 to 20 involve buses operating on a grade-separated roadway. Under each of these sets of alternatives various changes in other roadway, vehicle, and station components are made, as shown in Table 1 and Figure 2.

Parameters for Test Run

With the definition of the alternatives and the simulation model completed, a number of test runs were made. These test runs were made using a set of parameters that represented a reasonably high-volume system operating over a single route during an afternoon peak period. The parameters used for the test runs are given in Table 2. The implications of these parameters as well as of the assumptions used should be fully understood before applying the results of the research to a particular area. If such an application is being considered, further analysis should be made to adopt the model to local conditions.

Figure 1. Computer flow chart.

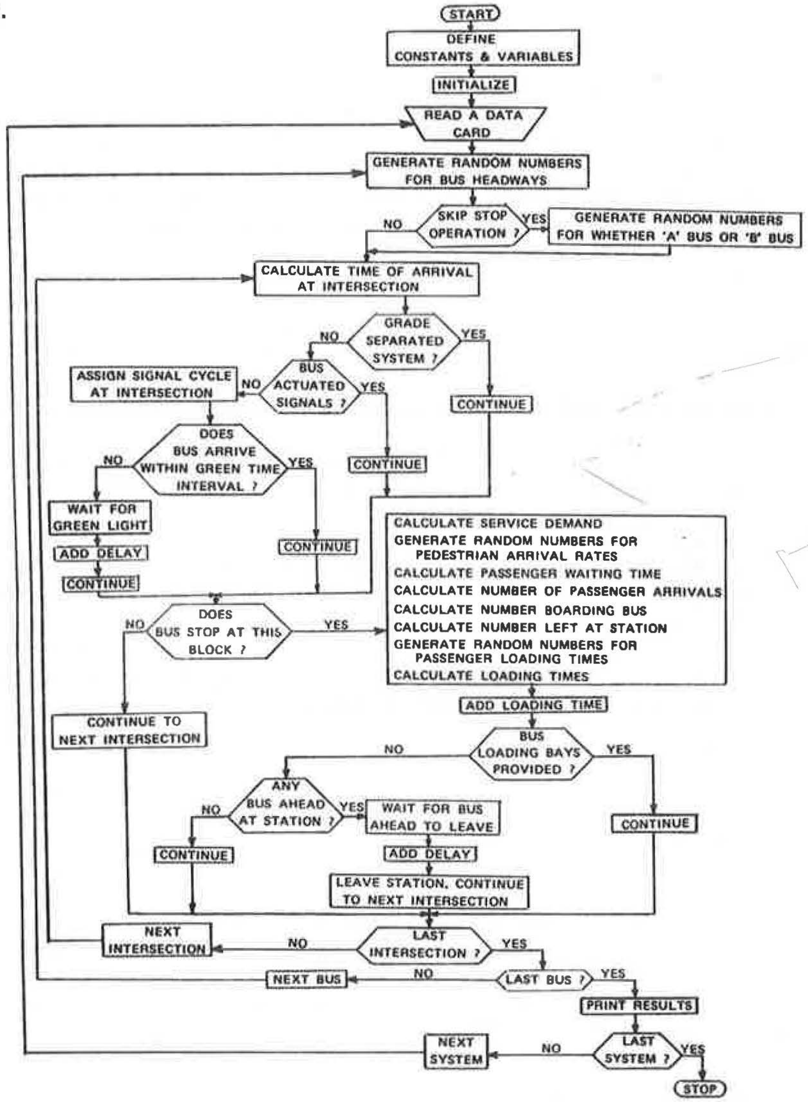


Table 1. Alternatives to be tested.

	Busway			Station Layout		Stopping Configuration and Distance Between Stations				Number of Doors		Fare Collection		Traffic Signals			Transit Vehicles	
System No.	Mixed Traffic	Exclusive Street	Elevated or Subway	Stops in Through Lane	Stops in Bus Bay	Each Bus at Every Third Block	Skip Stop and 2 Stations for Every 3 Blocks	Skip Stop and 1 Station for Every 2 Blocks	Skip Stop and 1 Station for Every 3 Blocks	1 for Each Movement	2 for Each Movement	Exact Fare When Boarding	No Fare Collection When Boarding	Fixed-Cycle Signals	Bus-Actuated Signals	No Signals	Large Bus (50 Seats)	Small Bus (30 Seats)
1	X			X		X				X		X		X			X	
2	X			X			X			X		X		X			X	
3	X				X	X				X		X		X			X	
4	X				X		X			X		X		X			X	
5		X		X			X			X		X		X			X	
6		X			X		X			X		X		X			X	
7		X			X			X[a]		X		X		X			X	
8		X			X			X[b]		X		X		X			X	
9		X			X				X	X		X		X			X	
10		X			X		X				X		X	X			X	
11		X			X		X			X		X			X		X	
12		X			X			X[a]		X		X			X		X	
13		X			X		X			X		X			X			X
14			X	X		X				X		X				X	X	
15			X		X		X			X		X				X	X	
16			X		X			X[a]		X		X				X	X	
17			X		X			X[b]		X		X				X	X	
18			X		X				X	X		X				X	X	
19			X		X		X				X		X			X	X	
20			X		X		X			X		X				X		X

[a] 'A' Stations and 'B' Stations at adjacent blocks.

[b] One block between 'A' Stations and 'B' Stations.

The afternoon peak hour was simulated because it was felt that it would be more critical than the morning, since boarding consumes more time than alighting. Predominant boarding also involves having the bus filled up, thus leaving bus patrons at stations awaiting the next arrival. The supply of buses during the peak hour is determined by the number of passengers to be served; both are treated as input variables. The test route is 12 blocks long, with 12 signalized intersections and from 4 to 8 stations, depending on the station spacing.

For the test runs a peak-hour bus flow of 100 buses per hour was used. This results in a close headway between buses, which has a subsequent effect on the results of the simulation. For example, buses may form a platoon or queues at intersections and at loading points. This causes delays when bus loading bays are not provided and vehicles are forced to wait for the bus ahead to clear the station. Station delay can occur if a large number of passengers must be loaded at a station. These delays can in turn affect the next bus waiting at the station. The nature of the delays incurred will depend on other characteristics of the alternatives, such as the loading system and the nature of the signal system.

The bus flow rate (100 buses per hour) was chosen to be typical of what could occur in the central area of a large city during rush periods. The current flow rate of buses on Wisconsin Avenue in Milwaukee is 70 buses per hour during the afternoon peak period, and bus flow rates ranging from 90 to 175 buses per hour are found on such streets as Michigan Avenue in Chicago, Euclid Avenue in Cleveland, Market Street in San Francisco, and Hillside Avenue in New York. Bus flows of 70 to 174 vehicles per hour are expected to occur in downtown Milwaukee under the proposed Milwaukee Area Transit Plan.

RESULTS

For each of the 20 systems, a total of 100 buses were tested in each computer run, and 10 consecutive runs were made. For each alternative system, the computer printout gives the statistics for each bus at each station, a summary for each bus, and a summary for the entire 100 buses for each system. The input characteristics used were kept the same for all the systems so that the alternatives could be tested under identical conditions and unbiased comparisons could be made.

The results from the simulation of the 20 alternative bus systems are summarized in Table 3, which gives the average values obtained from 10 independent runs for each alternative system. A sensitivity analysis of the computer printout showed that the results settled down to a steady-state condition quite rapidly.

Figure 3 shows the results given in Table 3. It is a diagram showing for each system the average total time required for each bus to complete its run though the test area. The total time is divided into subareas to show what portion of the total time is used for traveling, loading, signal delay, and station delay.

Starting with a basic system with no improvements (system 1), from left to right in the figure one can see that the average time used per bus decreases as alternative improvements are introduced to the systems. The difference between alternatives 1 and 2 is that in alternative 1 all buses stop at the same stations whereas for alternative 2 a skip-stop operation is employed, thereby reducing station delay. In alternative 3, bus loading bays are provided, thus eliminating the station delay. For alternatives 1 to 4, the buses are running in mixed traffic; for alternatives 5 to 13, they are running on exclusive streets; alternatives 11, 12, and 13 have bus-actuated signals; in alternatives 14 to 20 the busway is grade-separated. A stepwise decrease in travel time is evident, with the largest decrease occurring between buses in mixed traffic and on exclusive streets, i.e., between alternatives 4 and 5. Where bus-actuated signals are used in connection with exclusive streets and for the grade-separated systems, the signal delays are eliminated. Systems 14 and 15 are both grade-separated, have the same number of stops, and are identical in all other respects except that for alternative 14 the buses stop in the through lane whereas in alternative 15 bus loading bays are provided. One can clearly see the extra delay imposed on buses in alternative 14 as they have to wait for buses ahead at stations. It should be recalled that the flow rate used in these runs was 100 buses per hour. At such a rate buses would often have to wait in the through lane for a bus ahead to complete its loading, and a higher total time would result. For alternatives 10 and 19, the passengers were allowed to board through 2 doors, and no fares were collected while boarding. Figure 3 shows that this reduces loading time to about half that of boarding through 1 door while paying exact fare.

Examination of Individual Components

To obtain a more accurate indication of what time saving could be expected from each single improvement, systems with identical component options were examined, varying only the options for the component being analyzed. For example, when the roadway component was to be examined to see what effect running buses in mixed traffic, on exclusive streets, or on elevated structures would have on the system operation, systems with similar options were analyzed, varying only the options under the roadway component. Systems shown under the same "level number" in Figures 4 to 10 have identical options for all components other than the particular component under examination. Figures 4 through 10 show the average time used per bus under each option for a particular component when other component options are kept the same. The vertical distance between the lines in the figures then represents the difference in total time consumed, or time saving, between the respective options being tested.

Comparison of Mixed Traffic, Exclusive Streets, and Grade-Separated Busways—The effects of having buses run on exclusive streets or on grade-separated busways as compared to operating in mixed traffic are shown in Figure 4. As could be expected, the separation of buses from other traffic causes a reduction in travel times for the vehicles. The magnitude of the reductions varies according to what options are considered under the other components. The time savings to be expected range from 15 to 20 percent of total time used in the case of exclusive streets and from 25 to 35 percent for grade-separated busways, as compared to buses operating in mixed traffic.

In Figure 4, the fact that systems 1 and 14 are plotted under the same "level number" means that their options under all components other than the roadway component are identical, such as stopping in through lane, each bus stopping at every third block, one door for boarding while paying exact fare, and so on. Systems 2 and 5 are plotted at level II, and this again signifies their similar options under all other components but that these options are different from those under level I; in this case, the difference is the skip-stop operation realized at level II. Levels III and IV reflect still other option selections.

Comparison of Through Lane and Bus Loading Bays—The results in Figure 5 show that the provision of bus loading bays at stations so that all buses are free to proceed as soon as their loading is completed gives a time saving of from 15 to 25 percent as compared to systems where the buses stop in the through lane and are forced to wait until any bus ahead has completed its loading.

Comparison of Buses Stopping at Same Stations and Skip-Stop Operation—A time saving of from 5 to 15 percent for skip-stop operation is indicated by the model. Figure 6 shows that the time saving depends on whether the buses stop in the through lane (level I) or in loading bays (level II) at the stations. Where bus loading bays are provided, the time saving from skip-stop operation will be less because there is no station delay to be saved.

Comparison of Station Spacing—Three systems with buses running on exclusive streets (level I) and 3 systems with buses running on grade-separated structures (level II) were tested. The results are shown in Figure 7. By increasing the station spacing from 2 stations for every 3 blocks to 1 for every second block or 1 for every third block, the total time savings that can be expected are about 5 and 10 percent respectively. This is attributed to fewer station stops, which means fewer decelerations and accelerations and less time spent for the opening and closing of bus doors.

Comparison of Boarding and Fare Collection—The 4 systems tested are shown in Figure 8 with exclusive street systems at level I and grade-separated systems at level II. The cases where people board through 2 doors and pay no fare while boarding show a total average time advantage of from 10 to 15 percent over the conventional method of boarding through 1 door and collecting exact fare while boarding.

Figure 2. Visual display of alternative systems.

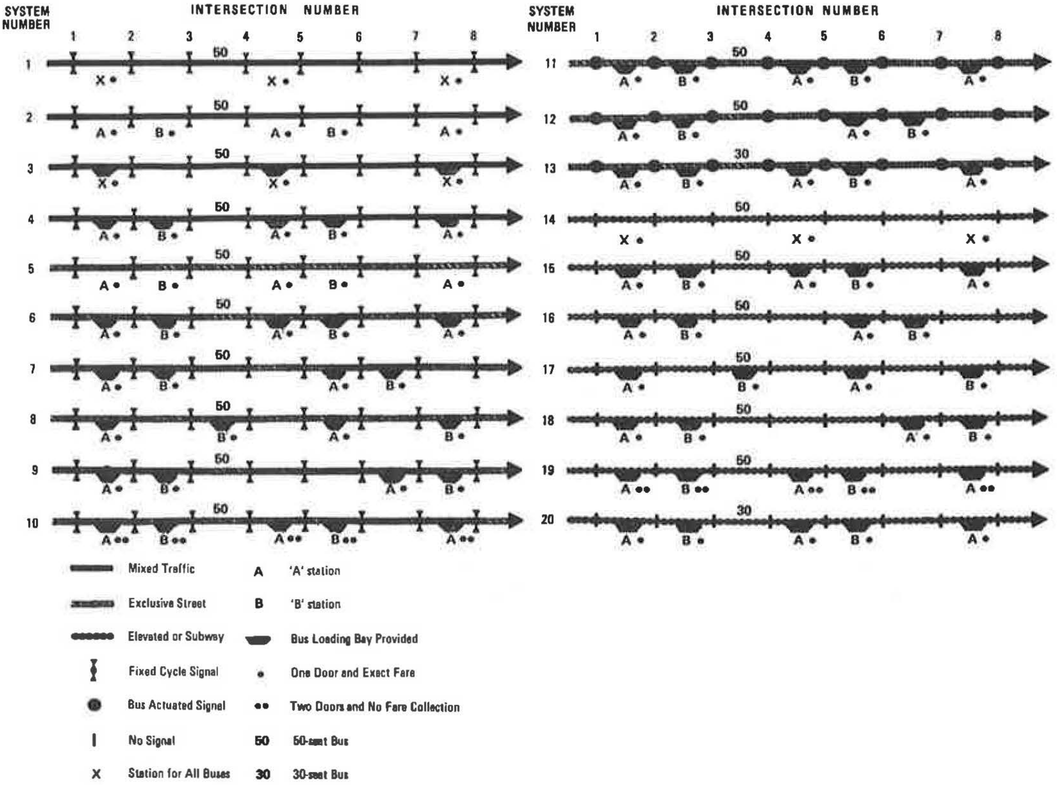


Table 2. Peak-hour input characteristics for test runs of model.

Characteristic	Amount
Size of area being tested (number of city blocks)	12
Maximum demand during peak hour (passengers per hour)	4,000
Minimum demand during peak hour (passengers per hour)	1,000
Peak hour bus flow (buses per hour)	100
Number of buses tested	100
Bus capacity (number of seats)	50
Maximum passengers allowed at one station	30
Minimum bus headway (seconds)	3
Cycle length for traffic signals (seconds)	60
Length of green time for traffic signals (seconds)	40
Time offset between adjacent traffic signals (seconds)	10

Table 3. Systems summaries.

System No.	Average Occupancy per Bus	Total Travel Time (min)	Percent of Total	Average Travel Time per Bus		Total Loading Time (min)	Percent of Total	Average Loading Time per Bus		Total Signal Delay (min)	Percent of Total	Average Signal Delay per Bus		Total Station Delay (min)	Percent of Total	Average Station Delay per Bus		Total Time Used (min)	Average Total Time per Bus		Efficiency Index (Adjusted) (occupancy/time used)
				Min	Pers.-Min			Min	Pers.-Min			Min	Pers.-Min			Min	Pers.-Min		Min	Pers.-Min	
1	41	402	47	4.0	165	129	15	1.3	53	74	9	0.7	30	253	29	2.5	104	858	8.6	352	1.00
2	41	401	57	4.0	165	130	19	1.3	53	68	10	0.7	28	99	14	1.0	41	698	7.0	287	1.24
3	46	405	65	4.0	186	147	23	1.5	68	77	12	0.8	35	0	0	0	0	629	6.3	289	1.56
4	42	404	66	4.0	170	135	22	1.3	57	74	12	0.7	31	0	0	0	0	613	6.1	258	1.46
5	42	294	51	2.9	123	134	24	1.3	56	59	10	0.6	25	88	15	0.9	37	575	5.8	241	1.54
6	45	293	59	2.9	132	144	29	1.4	65	59	12	0.6	27	0	0	0	0	496	5.0	224	1.92
7	39	290	62	2.9	113	123	26	1.2	48	55	12	0.6	21	0	0	0	0	468	4.7	182	1.74
8	39	289	62	2.9	113	125	27	1.2	49	54	11	0.5	21	0	0	0	0	468	4.7	183	1.77
9	31	286	67	2.9	89	99	23	1.0	31	45	10	0.5	14	0	0	0	0	430	4.3	134	1.52
10	45	297	68	3.0	134	71	16	0.7	32	70	16	0.7	31	0	0	0	0	438	4.4	197	2.17
11	43	275	66	2.8	118	139	34	1.4	60	0	0	0	0	0	0	0	0	414	4.1	176	2.21
12	39	275	69	2.8	107	123	31	1.2	48	0	0	0	0	0	0	0	0	398	4.0	155	2.05
13	26	278	77	2.8	72	84	23	0.8	22	0	0	0	0	0	0	0	0	362	3.6	94	1.53
14	42	255	37	2.6	107	133	20	1.3	56	0	0	0	0	294	43	2.9	123	682	6.8	286	1.30
15	44	255	65	2.6	112	139	35	1.4	61	0	0	0	0	0	0	0	0	394	3.9	173	2.34
16	38	253	67	2.5	96	122	33	1.2	46	0	0	0	0	0	0	0	0	375	3.8	142	2.16
17	38	253	67	2.5	96	122	33	1.2	46	0	0	0	0	0	0	0	0	375	3.8	142	2.15
18	31	252	72	2.5	78	98	28	1.0	30	0	0	0	0	0	0	0	0	350	3.5	108	1.85
19	41	254	80	2.5	104	65	20	0.7	27	0	0	0	0	0	0	0	0	319	3.2	131	2.70
20	27	256	75	2.6	69	86	25	0.9	23	0	0	0	0	0	0	0	0	342	3.4	92	1.68

Figure 3. Time used along route for each system.

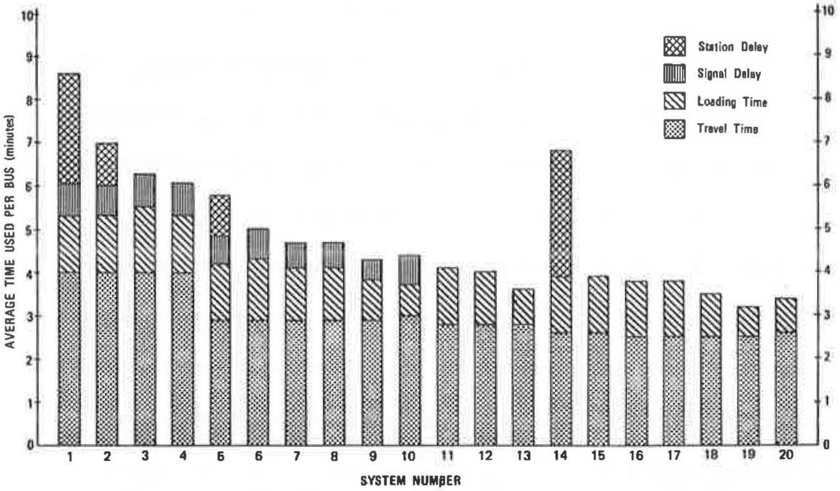


Figure 4. Time used per bus for systems having buses in mixed traffic, on exclusive streets, or on grade-separated structures.

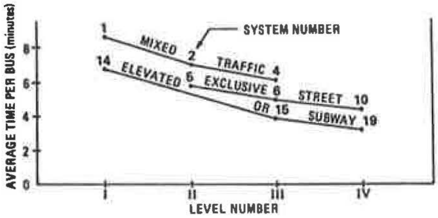


Figure 5. Time used per bus for systems having buses stop in through lane or in bus loading bays at stations.

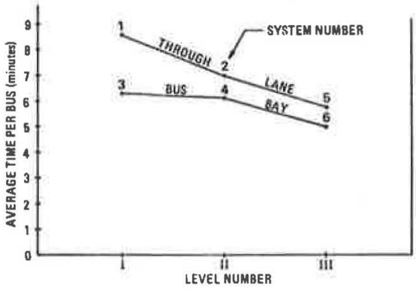


Figure 6. Time used per bus for systems having buses stop at the same stations or having skip-stop operation.

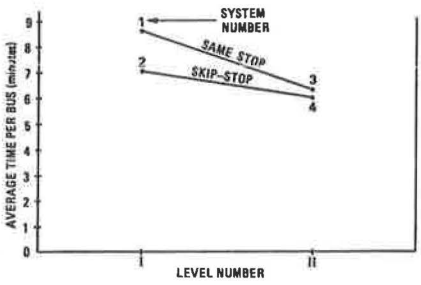


Figure 7. Time used per bus for systems having 2 stations for every 3 blocks, 1 station for every 2 blocks, or 1 station for every 3 blocks.

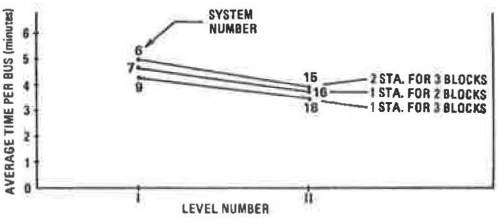
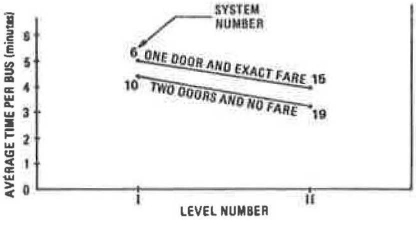


Figure 8. Time used per bus for systems with boarding through 1 door and payment of exact fare and for systems with boarding through 2 doors and no fare collection while boarding.



Comparison of Fixed-Cycle and Bus-Actuated Signals—Four systems having buses running on exclusive streets were tested with fixed-cycle signals and bus-actuated signals at intersections. At the fixed-cycle signals, the buses were given 40 seconds' green time from a 60-second cycle. The signals are progressive, with an offset of 10 seconds. Any cycle length, green time, and signal offset can be given simply by changing the number on the data card. From the input used in this test, the results show that by replacing fixed-cycle signals with bus-actuated signals one can expect a reduction in total time used of about 15 percent. The results are shown in Figure 9.

Comparison of Large and Small Buses—The results from the simulation of 2 systems having large (50-seat) buses and 2 systems using small (30-seat) buses are shown in Figure 10, with exclusive street systems at level I and grade-separated systems at level II. A time difference of 0.5 minute in favor of the smaller buses indicated that the use of small buses will reduce total running time by about 10 percent. This time reduction, however, was derived wholly from a reduction in boarding time because of the reduced carrying capacity of the smaller buses. As shown, the actual efficiency of systems having large buses was found to exceed that of systems using small buses.

Examination of Efficiency Ratings

In order to take into consideration the number of people carried as well as time consumed, a term called efficiency index was introduced. It is defined as the ratio of average bus occupancy to total time used through the test area, expressed as passengers per minute. The index was adjusted by a factor so that the basic system with no improvements (system I) would have an efficiency index of 1.0. For the 20 systems tested, the index has a range of from 1.0 to 2.7, as shown in Figure 11, with the high number indicating the most efficient system. The efficiency index was introduced primarily for the purpose of testing systems having vehicles of different seating capacity because, where the size of vehicles differs, a measure for time saving only will not give a true indication of the total benefits obtained. In Figure 11 the effect of using smaller buses rather than the conventional size with 50 seats can be examined by comparing systems 10 and 13 and 15 and 20. It was determined that, although the use of smaller buses will speed up operations, their reduced carrying capacity will cause the overall efficiency of operation to decrease by about 30 percent. All the systems can conveniently be measured by this index method; the increase in efficiency index will be in proportion to the percentage time saving found previously.

Staged Improvements

It will often be desirable to carry out transit improvements in stages, a strategy whereby the improvements are programmed for construction at a time when the demand warrants such action. By knowing the increase in efficiency that can be expected from various transit improvements, one can test, well in advance, alternative transit systems that will be needed to meet anticipated future demands. This will enable decision-makers to develop a program for planned expansion of their transit systems coordinated with other developments. Figure 12 suggests one stepwise improvement program by which the efficiency index can be increased from unity to 2.7. For example, it is found that an efficiency increase of, say, 30 percent is needed for downtown transit service within a certain time in order to maintain an adequate level of service. Figure 12 shows that the introduction of skip-stop operation and provision of bus loading bays at stations should accomplish this. With future improvements in mind, the provision of exclusive streets for buses, including, perhaps, bus-actuated signals at intersections, will further increase the efficiency. By improving boarding and fare collection methods and by grade-separating transit vehicles from other traffic, the efficiency can be given a further substantial increase.

CONCLUSIONS

This paper has described the development of a technique for the evaluation of the efficiency of alternative bus transit distribution systems in central areas. This was done through the use of a model that simulated the flow of buses through a downtown

Figure 9. Time used per bus for systems having fixed-cycle signals and for systems having bus-actuated signals.

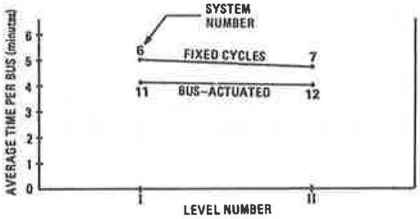


Figure 10. Time used per bus for systems with large buses and for systems with small buses.

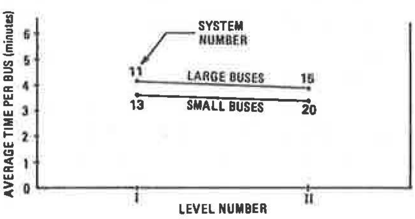


Figure 11. Efficiency indexes for the alternative bus systems.

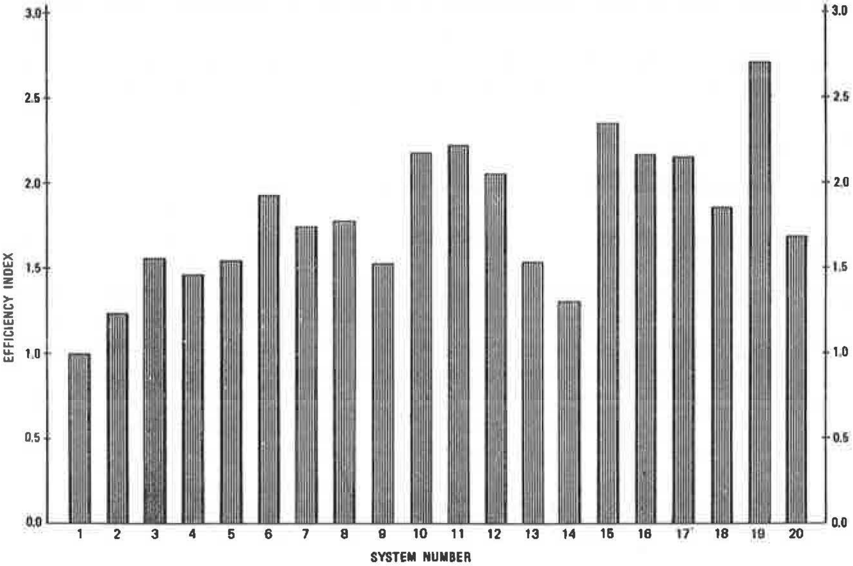
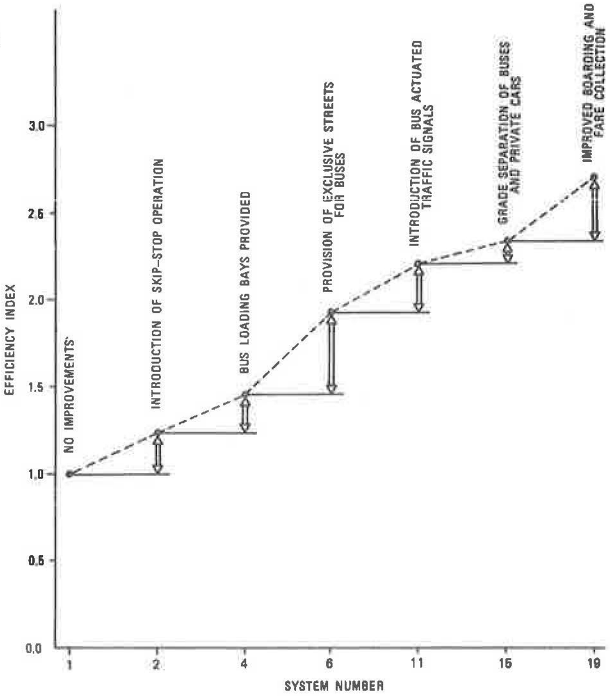


Figure 12. Increase in efficiency by introduction of improvements.



area. The simulation model proved to be a useful technique and demonstrated that substantial improvements in central area distribution can occur through the introduction of preferential bus treatments and facility improvements. Through a combination of several treatments, the operational efficiency of a bus system can be more than doubled as compared to conventional operation for the situations tested.

As compared to running buses in mixed traffic, the provision of exclusive bus streets or grade-separated busways yielding higher travel speeds will increase the system efficiency by as much as 15 to 20 percent and 25 to 35 percent respectively. By the installation of bus-actuated traffic signals at intersections, thereby reducing signal delays, the exclusive-streets systems can be made almost as efficient as the grade-separated ones, depending, of course, on the effectiveness of the signal actuation. At a supply rate of about 100 buses per hour, it was shown that providing bus loading bays at the stations could increase efficiency by 15 to 25 percent simply by the elimination of bus delays at the stations. Skip-stop operation contributes between 5 and 15 percent toward increased efficiency.

The tests for different station spacings indicated an efficiency increase of about 5 percent for every block increase in station spacing. However, one should keep in mind that an increase in station spacing will increase the walking distance for transit patrons, in addition to requiring large station areas. Also, excessive station sizes could complicate station operations and subsequently reduce efficiency.

During peak hours, when the service demand is heavy, the elimination of fare collection will allow passengers to board through both doors without delay for fare payment. This will reduce boarding times enough to allow an efficiency increase in the order of 15 percent. Although the use of smaller 30-seat buses, as compared to larger ones with 50 seats, will have a reduction in total running time of between 10 and 15 percent, the overall efficiency for the larger buses due to their higher carrying capacity was found to be almost 30 percent higher.

The model can be applied to test transit operation in any high-activity corridor after being calibrated to represent the characteristics of the specific area to be tested. It is capable of analyzing transit operation at various levels of demand, for any signal-cycle lengths, phase lengths, and progressive time offsets, in addition to any of the alternative improvement options discussed in this report. The results will provide the traffic and transportation planner with an insight into the benefits to be earned from certain actions and investments. The model is an effective tool that will allow the user to base decisions on expected benefits rather than on the unknown.

ACKNOWLEDGMENTS

We thank James Mackey of the Milwaukee County Expressway and Transportation Commission, Michael Ross of Barton-Aschman Associates Inc., and Frederick Wegmann and Walter Garvey of the University of Wisconsin—Milwaukee and the organizations they represent for their help and assistance on this project.

This report was produced as part of a program of Research and Training in Urban Transportation at the University of Wisconsin—Milwaukee sponsored by the Urban Mass Transportation Administration of the U.S. Department of Transportation. The results and views expressed are the independent products of University research and are not necessarily concurred with by the Urban Mass Transportation Administration or the U.S. Department of Transportation.

REFERENCE

1. Eriksen, Alf R. A Bus Simulation Model. Univ. of Wisconsin—Milwaukee, report to the Urban Mass Transportation Administration, Feb. 1972.