Transportation Systems Management Options to Improve Urban Bus Route Performance Using Computer Simulation

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In view of the increasing demand on public transport in medium-sized cities of the Third World and the limited resources available for improving bus transit, suitable transportation system management (TSM) strategies need to be applied. This study uses a computer simulation model to evaluate the impact of TSM options on the performance of a bus route in a medium-sized city in India. The simulation model was validated with data from a bus route in Tiruchirapalli, and various TSM strategies including increase in running speed, removal of bus stops, operation of special services, and combination of options were simulated. The simulation results were compared with earlier findings in Madras. The conclusions drawn may be extended to other routes in Third World cities. More than 40 percent of the trip time is spent in changing speed because of the presence of a large number of intersections and bus stops. However, increase in speed or speed change rates do not significantly influence the trip time. Removal of two and four bus stops reduces the travel time by 3 and 6 percent, respectively. Combination of removal of stops with an increase in speed and speed change rates by 10 percent doubles the reduction in travel time. The combination of increase in speed and speed change rates with removal of four stops enables the operation of two additional round trips, leading to better utilization of the existing fleet.

The population explosion and the accompanying urban migration have led to the phenomenal growth of cities around the world. Cities in the Third World countries such as India have evolved in a haphazard manner. With increased city sizes, trip lengths have increased, and the burden of commuter travel has fallen upon public transport as longer trips tend to discourage walking and cycling as convenient alternatives (*1*). This enhanced demand will have to be met by improvements to bus transit, because other alternatives such as suburban rail are highly capital-intensive and hence not suited to India. To derive the maximum benefit from the limited resources available for investment in bus transit, suitable transportation system management (TSM) strategies need to be implemented.

This study uses a computer simulation model to evaluate the impact of TSM options on the performance of urban bus routes. A simulation model developed for Madras (*2*) was substantially modified and applied to Tiruchirapalli (Trichy), a medium-sized city in India (*3*). Trichy differs significantly from Madras in area, population, and traffic composition. Parameters influencing bus operation such as route length, passenger demand, spacing of stops, and so on, are also different in the two cities. A number of TSM options have been tried on a typical route in Trichy with a view to identifying those measures that are suitable for Third World cities.

In the present study an effort was also made to combine compatible TSM options and arrive at an optimum combination that would result in maximum reduction in travel time. This reduction was translated into additional round trips that can be operated by the same bus fleet. The impacts of the various options in Trichy and Madras were compared wherever possible. It is hoped that the TSM options effective in the two cities can be applied to other bus routes in Third World cities.

SIMULATION MODEL

Most of the deterministic models developed for studying bus transit are oversimplified and neglect many aspects of real bus operation by forcing it into a restrictive mold to suit the needs of the model (*2*). The simulation technique with its inherent capability to model random environments is the ideal tool for the study of bus operation (*4*). Random conditions can be replicated in simulation models, facilitating comparison of the impacts of parametric changes under identical field conditions (*5*). Hence simulation has been widely used to model bus transit (*6–9*). The present model, written in GPSS (General Purpose Simulation System) language, is a microsimulation model in which every bus and every passenger is traced (*2*).

The different processes involved in bus operation are shown in Figure 1. The model divides the route into a number of segments bound by critical points at which the bus has to either slow down or stop. The critical points include bus stops, all types of intersections, and police-controlled pedestrian crossings. Buses are generated at the origin, and their movement is governed by the given speed and acceleration or deceleration rates. Passengers queue up at the origin and intermediate bus stops, and their movements are simulated using passenger destination probabilities.

The travel time of the passenger consists of walking time, waiting time, in-vehicle travel time, and concealed waiting time (*2*). Reduction of in-vehicle travel time in a bus route benefits not only the bus passenger, but also the transit operator, since more trips can be operated with the same bus fleet (*10*).

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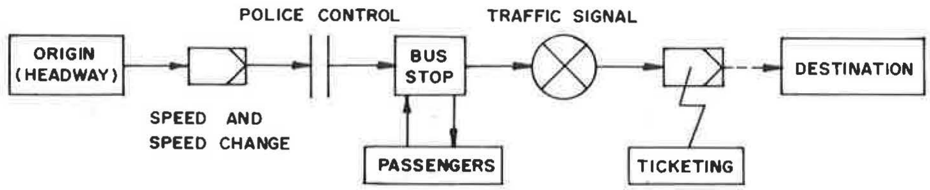

FIGURE 1 Schematic of urban bus route.

The total trip time comprises stopped time at bus stops, ticketing delay, intersection delay, time taken for speed change, and uniform running time. If all of the passengers are not issued tickets at the end of a fare stage, the bus waits at the last fare stage stop to complete the issue of tickets. Such a delay is termed the ticketing delay. Intersection delay consists only of the stoppages at intersections. Uniform running time is the time during which the bus runs at uniform speed.

MODEL VALIDATION

For validation of the model under the conditions in Trichy, a typical bus route from the central bus stand to the Main Guard Gate via Thillai Nagar was chosen (*3*). Various route details such as location of critical points, fare stage stops, origin headways, passenger demand at various points, and passenger destination probabilities were collected. Table 1 presents the parameters of the study route in comparison with the two routes in Madras (*2*).

In order to collect travel time statistics, six trips were made in buses along the route during the evening peak period. The total travel time and stopped time at bus stops were noted. With the above data the simulation model was run for a 2-hr peak period. The simulation was repeated under six different random number streams to minimize the bias due to random numbers. To maintain uniformity, the average of the six simulation runs is taken as the base case for validation and for analysis of options.

The simulation results and field values are compared in Table 2. The total travel time and bus stop time closely agree with the field observations. The *t*-test at the 5 percent level of significance shows that no significant differences exist between field values and simulation results. This indicates satisfactory validation of the simulation model.

From the results of the base-case simulation, the components of travel time were derived as percentage of total travel time and compared with the corresponding values for Madras (*2*) in Figure 2. The components of travel time are similar in both cities, with speed change time, uniform running time, and bus stop time constituting the major portion of travel time.

Speed change operations account for more than 40 percent of trip time, because of the large number of critical points at which the bus has to either slow down or stop. In Trichy, the speed change time is more than in Madras because of the closer spacing of critical points.

Ticketing delay is nearly zero in Trichy, because the buses are operated with two conductors. Intersection delay is also lower in Trichy, because there are fewer signalized and police-controlled intersections where the bus has to actually stop. Most of the intersections are priority-based and buses merely slow down. Uniform running time is the same in all cases.

SIMULATION OF OPTIONS TO IMPROVE BUS TRANSIT

The TSM options studied using the simulation model are

- Variation in nominal running speed,
- Variation in speed change characteristics,
- Removal of bus stops,
- Running of special services,
- Deployment of different types of buses, and
- Relocation of bus stops.

For the analysis of each option, six simulation runs were made using the same random number streams as those for the base-case simulation and the results were then averaged. The base-case results were compared with the simulation results of options under study, and the variations in travel time components under the influence of each option are summarized in Table 3. The 95 percent confidence limits of the mean total travel time established for each option with the use of the *t*-test are given in column 9. Column 10 gives the percentage deviation of the travel time under each option from that of the base case.

Variation of Running Speed

In order to study the effect of running speed on travel-time components, the bus route was simulated with the nominal speed of 35 kph increased by 10 and 20 percent.

TABLE 1 DETAILS OF SIMULATED ROUTES IN MADRAS AND TRICHY

Sl. No.	Parameter	Madras Route 18	Madras Route 15C	Trichy Route 36
1	Length (km)	11.2	9.8	7.5
2	Bus stops	16	17	18
3	Signalized intersections	8	5	0
4	Police-controlled intersections	2	3	4
5	Police-controlled pedestrian crossings	4	0	1
6	Uncontrolled intersections	6	11	10
7	Nominal headway at origin (min)	4	13	10
8	Average origin demand (pass/hr)	796	162	300
9	Average traffic volume (pcu/lane/hr)	785	850	915

TABLE 2 VALIDATION OF SIMULATION MODEL

Parameter	Average Field Value (sec)	Average Model Value (sec)	Difference Absolute (sec)	Difference Relative (%)	t-value at 5% Level
Total travel time	1582.5	1551.8	30.7	−1.9	0.54
Bus stop time	364.7	342.0	22.7	−6.6	0.55

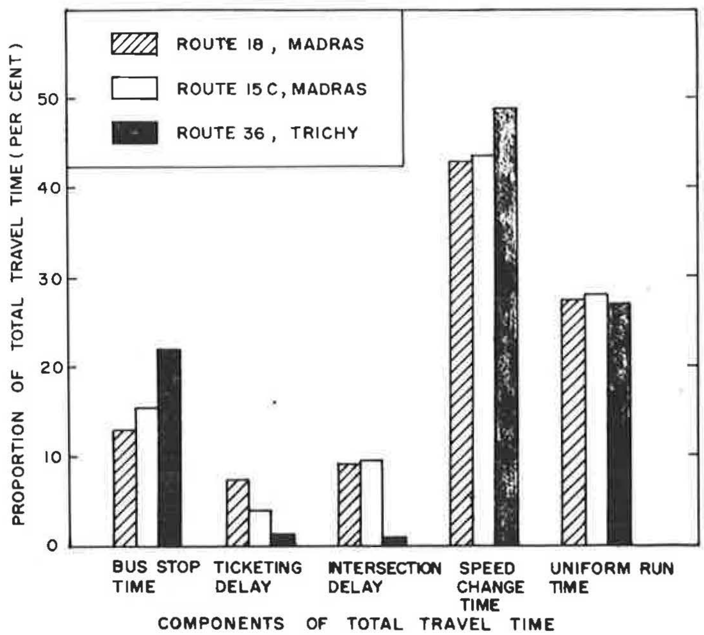

FIGURE 2 Components of total travel time in the simulated routes.

TABLE 3 EFFECT OF VARIOUS TSM OPTIONS ON TRAVEL TIME COMPONENTS

Sl. No.	Option	Bus Stop Time (sec)	Ticket-ing Delay (sec)	Inter-section Delay (sec)	Acc./Dec. Time (sec)	Uniform Run Time (sec)	Total Travel Time (sec)	95% Con-fidence Limits (sec)	Rela-tive Effect (%)
1	BASE CASE	342	18	7	769	415	1552	—[a]	—[a]
2	NOMINAL RUNNING SPEED								
	(a) Increased by 10%	341	35	24	815	348	1566	N.S.[b]	+0.9
	(b) Increased by 20%	341	38	25	838	304	1546	N.S.[b]	−0.4
	(c) Decreased by 10%	341	31	19	717	503	1611	N.S.[b]	+3.8
3	ACC. AND DEC. RATES								
	(a) Increased by 10%	341	40	32	710	431	1555	N.S.[b]	+0.2
	(b) Decreased by 10%	342	30	22	844	395	1633	±64	+5.2
4	BUS STOP REMOVAL								
	(a) Two stops	327	22	10	686	457	1504	N.S.[b]	−3.1
	(b) Four stops	305	30	10	613	494	1454	±57	−6.3
5	SPECIAL SERVICES								
	(a) Limited stop	77	10	22	305	610	1153	±45	−25.7
	(b) Express	22	0	27	159	686	884	±45	−43.0
	(c) Point-to-point	0	0	27	92	719	825	±44	−46.8
6	TYPE OF BUS								
	(a) Mini bus	330	6	29	769	417	1550	N.S.[b]	−0.1
	(b) Articulated bus	206	62	22	774	414	1476	±64	−4.9
	(c) Double decker	337	45	28	774	412	1579	N.S.[b]	+1.7
7	RELOCATION OF BUS STOPS								
	Distance from intersection								
	(a) Increased to 100m	346	17	28	777	412	1579	N.S.[b]	+1.8
	(b) Increased to 150m	344	17	24	786	401	1573	N.S.[b]	+1.4
	(c) Increased to 200m	345	19	19	793	339	1567	N.S.[b]	+1.3
8	ROAD TRAFFIC								
	(a) Increased by 10%	343	33	22	765	433	1596	N.S.[b]	+2.8
	(b) Increased by 20%	343	35	21	750	463	1613	N.S.[b]	+3.9
	(c) Increased by 30%	342	34	23	732	490	1622	±63	+4.5
9	PASSENGER DEMAND								
	(a) Increased by 10%	363	42	35	775	414	1632	±58	+5.2
	(b) Increased by 20%	379	54	24	775	413	1644	±58	+6.0
	(c) Increased by 30%	395	67	25	771	414	1672	±52	+7.7
10	COMBINATION OF OPTIONS								
	(a) Options 2a & 3a	345	28	25	761	361	1518	N.S.[b]	−2.2
	(b) Options 10a & 4a	311	22	20	677	404	1434	±70	−7.6
	(c) Options 10a & 4b	276	22	24	607	442	1371	±71	−11.7

[a] Not Applicable.

[b] Not significant at 5 per cent level.

TABLE 4 COMPARISON OF SIMULATION RESULTS IN MADRAS AND TRICHY

		Madras				Trichy	
		Route 18		Route 15C		Route 36	
Sl. No.	Option	Travel Time (sec)	Relative Effect (%)	Travel Time (sec)	Relative Effect (%)	Travel Time (sec)	Relative Effect (%)
1	BASE CASE	2297	—[a]	2074	—[a]	1552	—[a]
2	NOMINAL RUNNING SPEED						
	(a) Increased by 10%	2264	N.S.[b]	2051	N.S.[b]	1566	N.S.[b]
	(b) Increased by 20%	2228	−3.0	2024	−2.4	1546	N.S.[b]
3	BUS STOP REMOVAL						
	(a) Two stops	2245	−2.3	2026	−2.3	1504	−3.1
	(b) Four stops	2187	−4.8	1964	−5.3	1454	−6.3
4	SPECIAL SERVICES						
	(a) Limited stop	1629	−29.1	1405	−32.3	1153	−25.7
	(b) Express	1481	−35.5	1346	−35.1	884	−43.0
	(c) Point-to-point	1431	−37.7	1328	−36.0	825	−46.8
5	TYPE OF BUS						
	(a) Mini bus	2272	N.S.[b]	2104	N.S.[b]	1550	N.S.[b]
	(b) Articulated bus	2014	−12.3	1885	−9.1	1476	−4.9
	(c) Double decker	2060	−10.3	1933	−6.8	1579	N.S.[b]

[a] Not Applicable.
[b] Not significant at 5 per cent level.

An increase in running speed of 10 or 20 percent causes no significant change in the total travel time. Small changes in nominal running speed do not affect the travel time, because of the large number of critical points along the route at which the bus has to either slow down or stop. Table 4 shows that the effect of increased running speed on travel time is more prominent in Madras, and this can be attributed to the greater spacing of critical points and the greater orderliness in traffic.

Increase in speed is associated with increased accident risk. Additional expenditure and effort to increase the running speed cannot be justified, especially if the route has a large number of intersections and closely spaced bus stops.

Modification of Speed Change Characteristics

The nominal acceleration rate used in the model is 0.34 m/sec^2 and the deceleration rate is 1.03 m/sec^2. The acceleration and deceleration rates were increased by 10 percent and the system was simulated. Although speed change time forms a major part of total trip time, the increase in acceleration and deceleration rates causes no significant change in travel time. This is similar to the result obtained in Madras (*2*). Speed change time is converted to uniform running time and the net effect becomes negligible, and therefore, this option may not be effective.

Removal of Bus Stops

The effect of bus stop removal was studied by simulating the bus operation with removal of two and then four stops. Passengers at the removed stops were redistributed to the adjacent stops in inverse proportion to the walking distance.

The total travel time is reduced by about 3 and 6 percent with the removal of two and four stops, respectively. Figure 3 shows the effect of stop removal on travel time in Trichy and Madras. It can be seen that stop removal has a greater effect on total travel time in Trichy than in Madras. Removal of stops is a very effective option to reduce the travel time, especially in Trichy where the average stop spacing is as low as 400 m.

Special Services

Limited stop, express, and point-to-point services were simulated with a number of assumptions to arrive at the savings in travel time that can be achieved by operating special services. Total travel time decreases by about 30 percent when special services were operated. The effect of special services is more pronounced in Trichy because of the lower stop spacing in the city. Long-distance passengers will benefit more from the operation of special services. However, this will reduce the frequency at intermediate stops and the effective waiting time of passengers at certain stops will increase.

Type of Bus

Queue length and waiting time at bus stops depend on the capacity of the bus. The normal Indian bus has a nominal

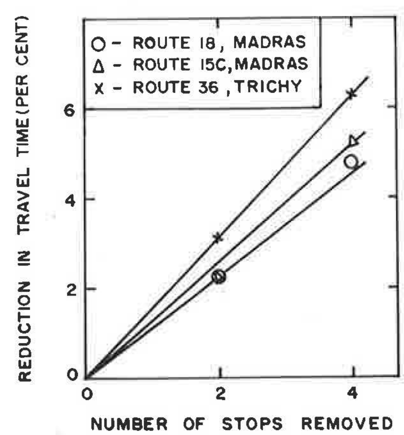

FIGURE 3 Effect of removal of stops on travel time.

capacity of 67. Other types of buses such as minibuses, articulated buses, and double-decker buses have capacities of 44, 97, and 103, respectively, and were simulated on the route.

The total travel time for minibuses does not register any significant change. Because of the presence of four doors in the articulated bus, the bus stop delay decreases, reducing the travel time by a significant 5 percent. There is no significant change in travel time parameters when a double-decker is operated. The reduction in travel time in Madras with the operation of articulated buses and double-deckers is much greater (see Table 4). This can be attributed to the reduction in ticketing delay achieved by using two conductors. Deployment of high-capacity vehicles reduces passenger waiting time and queue length at intermediate stops considerably.

The roads in Trichy are generally narrow, overcrowded, and inadequate to serve the present traffic (*11*). Minibuses are more suitable for narrow roads, and their introduction may lead to a general improvement in traffic conditions. If wider roads are available, high-capacity vehicles may be introduced to reduce passenger waiting time.

Relocation of Bus Stops

Bus stops located near intersections impede the movement of other vehicles and increase accident risk at the intersection. The route under study has five bus stops located at less than 50 m from intersections. These bus stops were moved away in steps of 50 to 200 m and the bus route was simulated to detect any significant changes in relevant parameters.

The simulation results show that relocation of stops causes no significant change in travel time or other relevant parameters. Therefore it is recommended that bus stops be located at a reasonable distance from intersections, and further studies are required to determine the optimal distance.

Increase in Passenger Demand and Road Traffic

Factors affecting bus operation, such as passenger demand and road traffic, may increase over the course of time because of development in the city. The model was used to predict the effects of such changes.

Both the parameters were increased by 10, 20, and 30 percent individually and simulation runs were made. The impact of increase in passenger demand and road traffic on journey speed is shown in Figure 4. The average journey speed in the route is 17 kph. Figure 4 shows that passenger demand influences the journey speed more. The effect of road traffic on the routes in Madras and Trichy is more or less the same, whereas an increase in passenger demand in Madras reduces the journey speed more, because the buses there are already overcrowded. When passenger demand increases, waiting time and queue length increase, especially at intermediate bus stops because of the ceiling on capacity.

COMBINATION OF OPTIONS

In any TSM strategy, a combination of compatible options is preferable to applying individual measures. An effort has been made to identify an optimum combination that will bring about substantial improvement to the operation of bus transit. The results of the simulation of combination of options are presented in Table 5.

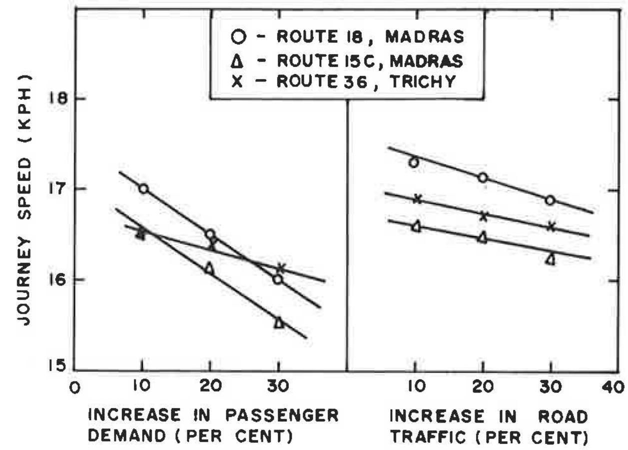

FIGURE 4 Effect of passenger demand and road traffic on journey speed.

Increase in speed and acceleration or deceleration rates are compatible, and a combination of these two options was simulated on Route 36 in Trichy. The results show that no significant change occurs in any of the major components of travel time. The combination is not effective because of the large number of critical points along the route. In order to make the above combination more effective, it was applied in conjunction with stop removal. When two and four stops were removed, the travel time was reduced by 7 and 12 percent, respectively. Bus stop delay and speed change time register significant reductions leading to substantial savings in travel time.

A number of measures have to be implemented to increase the speed and acceleration or deceleration rates. Improvement of road geometry, traffic segregation, proper pedestrian facilities, and effective implementation of traffic rules improve the road conditions. On the other hand, any increase in speed entails higher accident risk. Proper facilities for pedestrians and cyclists must be provided to minimize the risk. The simulation results indicate that improvement in road and traffic conditions combined with the removal of closely spaced stops leads to substantial savings in travel time.

SIGNIFICANCE OF TRAVEL TIME SAVINGS

In developing countries, saving of 1 or 2 min of travel time may not be very significant as perceived by the bus passenger

TABLE 5 EFFECT OF COMBINATION OF TSM OPTIONS

Sl. No.	Parameter	Percentage change due to option: Speed +10% Acc. and Dec. Rates +10% [1]	[1] and Two Stops Removed [2]	[1] and Four Stops Removed [3]
1	Total travel time	−2.2	−7.6	−11.7
2	Bus stop time	0.0	−9.1	−19.3
3	Acc. and dec. time	−1.0	−12.0	−21.1
4	Uniform running time	−13.0	−2.7	+6.5
5	Overall waiting time	−10.7	−15.8	−28.8

TABLE 6 TIME SAVINGS REQUIRED FOR ADDITIONAL ROUND TRIPS

Extra Round Trips	Extra Time Required (sec)	Time to be Saved per Trip in Peak (sec)	Proportion of Total Trip Time Saved (%)
1	1560	64	4.3
2	5248	170	10.9

TABLE 7 TSM OPTIONS LEADING TO ADDITIONAL ROUND TRIPS

Sl. No.	Option	Proportion of Total Trip Time Saved (%)	Number of Extra Round Trips
1	Removal of 4 stops	6.3	1
2	Articulated bus	4.9	1
3	Increase in speed and acc. & dec. rates with removal of 2 stops	7.6	1
4	Increase in speed and acc. & dec. rates with removal of 4 stops	11.7	2

(*12*). But by reducing the time taken for one single trip, additional round trips can be operated by the same bus in a day, and this will lead to better utilization of the bus fleet with an increase in transport supply.

An attempt has been made to determine the travel time saving required for operating one or two extra round trips on Route 36 in Trichy. Each bus is operated for 16 hr, from 6:00 a.m. to 10:00 p.m.; 6 of these hours are peak period and 10 of these hours off-peak. Trip time during off-peak period is assumed to be 90 percent of that during the peak period. One hour will be lost in shift changes and therefore 15 hr is available for effective operation. The bus is assumed to have a layover of 5 min at each end.

The time savings required for making additional round trips are shown in Table 6. Savings of 4 and 11 percent in travel time will enable one and two more round trips, respectively. The TSM options resulting in the required time savings are given in Table 7. Removal of low-demand stops proves to be the most effective option from the standpoint of additional round trips.

CONCLUSIONS

From the simulation study of a bus route in Trichy and comparison with the results obtained in Madras, some general conclusions can be drawn about the operation of bus routes in Third World countries. Of the total trip time, more than 40 percent is spent in acceleration and deceleration, because of the presence of a large number of intersections and other critical points. The journey speeds on the routes in Trichy, as well as in Madras, are as low as 17 kph because of the high frequency of critical points and heavy passenger demand.

TSM options can be implemented to reduce travel time. Increase in running speed or acceleration and deceleration rates does not influence the travel time much, especially on routes with a large number of bus stops and intersections. Removal of two and four stops reduces the travel time by about 3 and 6 percent, respectively. Low-demand or closely spaced stops may be removed even though this will make some of the passengers walk further. Operation of special services will reduce the travel time by more than 30 percent, and this measure will be highly beneficial to long-distance passengers.

Location of stops very near intersections impedes other vehicles and leads to an increase in accident risk. Relocation of such stops will cause no significant change in any of the travel time parameters. Such a measure is recommended for reducing general delay and accident risk at intersections.

Combination of compatible options brings about significant reduction in travel time. Increasing the speed and acceleration and deceleration rates with removal of certain low-demand, closely spaced stops is the optimum measure to get maximum savings in trip time. Removal of four stops in this combination reduces the travel time by more than 10 percent.

Additional round trips can be operated every day by a bus if significant reduction in trip time can be achieved. Removal of four stops with increase in speed and acceleration and deceleration rates by 10 percent will enable operation of two more round trips.

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