Dynamic scheduling of buses on a corridor and sensitivity analysis for generation of primary bus routes

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ABSTRACT : A city bus route on a major corridor has problems of high variation in passenger demand, high desired frequency of bus movements and different patterns of passenger arrivals as bus stops. The system of fixed headway operation cannot handle the above complexities. This paper presents a model to improve the system operation by adopting dynamic scheduling of buses. The model simulates the flow of passengers at each stop and the movement of buses along the route. The model output is used for optimal design of the dynamic headway. The model is tested by simulating the circular bus transit on the Ring Road system of Delhi .A series of simulation experiments are made and the dynamic scheduling is designed for 121 bus trips during the day in each direction. Comparison of the proposed dynamic scheduling with the existing fixed scheduling clearly demonstrates that dynamic scheduling provides better level of service.

Key words**:** Scheduling, Bus, dynamic, simulation, passenger

RESUME: Etablir une ligne de bus urbain sur un axe principal pose les problèmes de la grande variabilité de la demande de transport, du niveau élevé de fréquence souhaité, ainsi que de la diversité des schémas d'arrivée des voyageurs aux arrêts. Une desserte à intervalles fixes ne peut gérer cette complexité. Cet exposé présente un modèle pour améliorer le mode opératoire par la programmation dynamique des bus. Il simule un flux de voyageurs à chaque arrêt, ainsi que le déplacement du bus sur l'itinéraire. Les résultats du modèle sont utilisés pour optimiser un système de fréquences dynamiques. Le modèle est testé en simulant le parcours circulaire sur le « périphérique » à Delhi, et l'on réalise une série d'expériences simulées pour 121 voyages de bus dans la journée, couvrant toutes les directions. La comparaison du système dynamique proposé avec les intervalles fixes existants montre clairement que la programmation dynamique fournit un meilleur niveau de service.

Mots clés : programmation, bus, dynamique, simulation, voyageurs

1. INTRODUCTION

The phenomenal growth of cities in developing countries like India in past two or three decades has caused rapid rise in ownership of private automobile and thus necessitated a radical thinking of urban transport policies and programs. The main urban transportation problems like traffic conjunction, air pollution, environmental degradation, higher road accidents, increased inaccessibility of under privileged and waste of energy have provided convincing evidence that drastic action must be taken to provide or improve the urban transit system in order to alleviate these problems.

Among various means of public transportation, the bus transport is bound to dominate because of its door-to-door accessibility and flexibility in operation. Although the demand for bus transportation is high, poor planning strategies and inefficient operational methodologies are the cause of the heavy losses incurred by many bus operators mainly in public sector.

Among many issues of direct concern such as route design, bus allocation, bus scheduling, crew scheduling, maintenance scheduling, the design of bus routes and bus scheduling may be considered the primary one. Optimally designed bus scheduling can radically improve the performance of the system.

2. OBJECTIVES AND SCOPE OF STUDY

This study aims to develop a system for dynamic scheduling of direction-oriented routes by simulating the passenger demand on the different stops of the route and the movement of buses along the route. This proposed interactive graphic package for simulation and dynamic scheduling involves:

- Generation of passengers at different stops according to different probability distributions.
- Simulate the movement of buses from one stop to the other and scanning of passengers in the buses and the stops.
- Collection of information about the queues at different stops and estimating the statistics of passengers with respect to waiting time. Decisions are made about the optimal scheduling of additional buses that may be available.
- Showing the animation of vehicles movement from one stop to other on network and giving instantaneous information about stops and buses.

This study also aims to test the sensitivity of parameters involved in generation of destination oriented primary routes for a large network. The parameters selected for sensitivity are:

- Meandering factor to be adopted for generation of routes.
- The cutoff demand level for primary routes.

3. DEVELOPMENT OF MODEL FOR SCHEDULING

This model simulates the public bus transportation system on a corridor network of a city for given travel demand using heuristic approach. This model simulates at micro-level the arrival of passengers at all stops as per different pre-defined probability distributions, and the movement of buses from one stop to others [1,2,3]. The salient features of this model are:

- For each stop, passengers are generated as per pre-defined probability distributions and its specified parameters.
- This model simulates simultaneously the flow of passengers at all stops and movement of buses between all stops of network
- It shows the movement of buses from one stop to other by mode of Animation.
- It suggests deployment of an Additional bus from any of the terminals with the aim of maximizing the saving in passenger waiting time based on heuristic approach. The model is flexible enough so that user can accept or reject the suggestion made by simulation model.
- This model is involved with graphic user interface (GUI) [4,5]. User can obtain the information about all stops, buses and passengers at any instant of time. Simulation can be interrupted at any instant of time. The flow diagram shown in figure1. gives a precise idea of how the model works.

The simulation starts at the system time, which is defined as the time 10 minutes before the minimum of the departure time of the first bus of all stops.

3.1 GENERATION OF PASSENGERS

The arrival probability distributions of passengers may be Exponential distribution or Normal distribution. This model assumes that all the passengers are aware of the bus timings from each stop. Inverse transformation technique is used to generate exponential random variate and polar method is used to generate normal variates.

3.2 ASSGINING THE DESTINATIONS AND DIRECTION

Random destinations to the passengers are assigned. Each element of O-D matrix represents daily demand from one stop to the other. The initial O-D matrix is manipulated in such a way that each element of O-D matrix represents cumulative percentage of trips from one stop to the other. A random variate will be generated and if that random number matches with any block of cumulative percentage of trips of all destinations for a given stop, that stop will be assigned as destination. If the destination identification number is greater than the origin stop, the direction of movement will be taken as clockwise otherwise anticlockwise.

3.3 SCANNING STOPS AND BUSES

For each one-minute increment of system time, the following steps will be taken for each i^{th} stop.

- Get the sequence number of stop.
- Calculate total number of passengers, total clockwise passengers and total anti-clockwise passengers.
- Obtain the next bus to go, its id number, time of departure and direction of movement.
- If system time is equal or more than departure time of bus, that bus is ready to depart. Boarding and Alighting of passengers to and from the bus at the stop[i] is calculated .
- If system time is less than the bus time, it means that the bus has not arrived at the stop[i].

- The same above steps will be carried out for [i+1]th stop.

3.4 BOARDING AND ALIGHTING OF PASSENGERS

- Scan the passengers of bus, passengers in the bus having their destination equal to the stop number are unloaded.
- Count number of passengers in the bus.
- Compare with maximum bus capacity
- If number of passengers in bus is equal to bus capacity, no passengers are allowed to board the bus.
- If number of passengers in the bus is less than the bus capacity, load the first passenger from passengers queue at the stop depending upon the arrival time of passenger.

3.5 DEPARTURE OF BUS FROM STOP

If there is no passenger at stop [i] or there is no space in bus for passengers to accommodate or alighting and boarding of passengers is finished then allow the bus to depart the stop. Delete that bus from the bus-queue and update the bus-queue. Once the bus is moved out of stop[i] the same procedure will be repeated for the next stop.

3.6 STRATEGY FOR FINDING THE BEST STOP TO PROVIDE ADDITIONAL BUS

At each fixed increment of the system time, all stops are examined to find the best stop, which can provide the maximum saving in waiting time of passengers. This operation is carried out in two steps.

- *SELECTING THE ALTERNATIVES*

For a stop to be an alternative the following conditions should be satisfied:

i) The stop should be a Terminal and that should have at least one extra bus to provide.
ii) There must be at least some minimum passengers at stop. This condition is imposed keeping in view of operator's benefits. In this model. 25 passengers are considered as minimum number of passengers.
iii) There must be no bus at stop with departure time less than or equal to system time plus some extra minimum period. In this model 5 minutes as minimum period is taken i.e according to the time-table if there is no bus up to 5 minutes time it may consider for an alternative.

If a stop satisfies all the above three conditions, then it is taken as an alternative otherwise no additional bus will be suggested. If there is only one alternative that stop will be considered as best stop and an additional bus will be suggested. If there are alternatives greater than one, evaluation of alternatives will be made.

- *EVALUATING THE BEST ALTERNATIVE*

For each alternative the saving in passengers waiting time will be calculated, then the alternative, which has maximum saving in waiting time, will be considered as the best stop. The steps to be taken to evaluate the best alternative are:

i) Get the bus time from the departure time of next bus from stop[i].
ii) Calculate the time difference between system time and bus time.
iii) If an additional bus is scheduled for stop[i], it will save the waiting time of each passenger by time difference.
iv) Depending on the direction of bus calculate the passengers at that stop who can be served by extra bus.
v) Total saving in waiting time is the product of passengers in the bus and time difference.

Similarly, compute the saving in waiting time for all stops. A stop with maximum saving in waiting time will be taken as best stop.

4. PACKAGE ILLUSTRATION

'SCHEDUL' (Name of the package) is an interactive graphic package for dynamic scheduling of buses on a corridor. The graphic capabilities of the package may be practically useful for decision-making. The scheduling can be carried out with the interaction of user or automatically. This program is written in c++ language on turbo c++ platform. This package shows the movement of vehicles from one stop to the other by mode of "Animation". It allows the user to get information about different statistics in the form of:

i) on-line information about all stops on the screen.
ii) on-line information about buses on the screen
iii) on-line information about passengers on the screen.
iv) Information about the additional buses scheduled, new time table, queues formed at different stops and the average passengers waiting time can be obtained from output files.

5. CASE STUDY ANALYSIS

The model is tested for the ring road system of New Delhi. The ring road is a major corridor in the national capital, the daily passenger demand on the ring road is over 60,000 and total length of the ring road is around 47 km. Since passenger demand on the ring road system is very high requiring large number of buses, a bus route name 'MUDRIKA' operates at a very high frequency to satisfy this demand in clockwise and anti-clockwise directions.

The input for this model is obtained from the data collected from primary surveys, and secondary sources for the study 'Optimal Design of Urban Bus System' conducted by RITES for New Delhi Metropolitan area [6,7]. The total number of nodes on the ring road is found to be 76. As some of these are closely spaced, it would be difficult to show the animation on the screen. Hence some closely spaced nodes are merged into single major nodes, thus having 31 major stops on the ring road network. The O-D matrix for the 31 stops is then obtained by merging the O-D demand of smaller nodes with that of identified major stops. Six terminals are identified out of 31 stops on the ring road based on the total demand from each stop. Passenger link flow on each link is determined from the Demand matrix.

The aim of study is to simulate the movement of buses for peak period only. The field studies [7] indicate that in Delhi both morning and evening peak periods are of 3 hours duration and each caters to 25 percent of the daily demand. Morning peak period is from 7.30 a.m. to 10:30 a.m. and the evening peak period is from 5:00 p.m. to 8:00 p.m. The average link flow for the morning peak period i.e 25 percent of daily passenger link flow approximates 6,000 and taking load factor of 60 passengers per bus, 100 buses need to be operated. As all terminals are equally important to start with, equal number of buses is taken for all terminals. Initially 17 buses are taken for a terminal, with headway of 20 minutes in each direction. Assuming constant speed of 15 minutes the travel time on each link is calculated in terms of minutes.

The initial time table is then prepared. Considering the direction of movement of bus on the ring road, and its starting terminal the next destination is obtained, and the departure time of the bus is computed.

5.1 OUTPUT OF THE SIMULATION MODEL

The simulation process is started at 7:30 hrs and terminates at 10:30 hrs, thus covering the morning peak period. The initial buses taken were 100. This model suggests additional 21 buses to ply on the ring road. If all the additional buses are accepted, the details of additional buses scheduled are given in Table 1.

Table 1.Additional buses suggested by the model

Bus number	Starting terminal	Starting Time	Direction
101	8	7:25	CW
102	1	7:35	CW
103	8	7:45	ACW
104	18	8:05	CW
105	14	8:20	ACW
106	18	8:40	CW
107	29	8:50	CW
108	29	8:55	ACW
109	29	9:00	CW
110	14	9:05	CW
111	14	9:10	ACW
112	23	9:15	CW
113	14	9:20	CW
114	23	9:25	CW
115	1	9:30	CW
116	14	9:35	CW
117	1	9:40	ACW
118	8	9:45	ACW
119	23	9:50	ACW
120	18	9:55	CW
121	23	10:25	CW

The model also gives average waiting time of passengers, average queue length, maximum queue length formed at each stop and the saving in waiting time at all stops because of scheduling 21 additional buses.

With the initial buses taken on the network as a sensitivity parameter, different simulation runs are made for 6 different levels by varying initial buses from 90 to 140. As the total number of buses operating on the network increased from 115 to 158, waiting time has reduced from 8.06 to 6.55 min. (Table 2). This indicates that with the increase in number of buses, the level of service provided to the passengers has improved. When 90 buses are taken initially, the waiting time of passengers is high and some passengers are not served. This indicates the failure of the system. Results also show that when the number of buses is increased beyond 139, there is hardly any change in waiting time of passengers. This may be the optimal dynamic schedule for the ring system.

Table 2. Statistics for different levels of initially planned buses

No. of Initial Buses	Avg. Wait time of all Passengers (minutes)	Avg. Queue length	Maximum Queue Formed	Additional Buses	Total Buses
90	8.06	24.82	110	25	115
100	7.86	23.25	105	22	122
110	7.65	23.08	103	19	129
120	6.87	21.35	102	19	139
130	6.83	21.74	102	18	148
140	6.55	20.22	100	18	158

With the number of terminals as a sensitivity parameter, different experiments are conducted. Taking the number of initial buses 100, simulation runs are taken with 4,6 and 8 terminals. As the number of terminals has increased from 4 to 8 the average time of passengers has increased from 8.19 to 7.64 minutes and the average queue length has reduced from 26.58 to 22.17 (Table 3). This indicates that system performance has improved with increased number of terminals without any appreciable change in the total number of buses required for scheduling.

Table 3. System performance with different terminals (initial buses=100)

No. of Terminals	Avg. Wait time of pass. (minutes)	Avg. Queue	Max. Queue	Additional Buses Suggested	Total buses
4	8.16	26.58	120	21	121
6	7.86	23.25	105	21	121
8	7.64	22.17	103	22	122

To compare the effect of dynamic scheduling with fixed scheduling one more simulation experiment is conducted, with number of buses available remaining same for both cases. The results obtained demonstrated clearly [8] that the dynamic scheduling provides better level of service (Table 4).

Table 4. Comparison between dynamic scheduling and fixed scheduling

	Dynamic scheduling	Conventional scheduling
Total buses operated	129	130
Average waiting time (minutes)	7.65	8.56
Avg. Queues lengths	23.08	24.03
Maximum queue lengths	103	124

6. SENSTIVITY ANALYSIS FOR GENERATION OF PRIMARY BUS ROUTES

The parameters selected for sensitivity analysis are 'meandering factor' to be adopted for generation of routes, and the minimum demand level for primary routes. A set of experiments were conducted by keeping minimum cutoff demand as 9000 passengers per day, limits for route ranging between 8.0 to 25 Km, minimum inter terminal demand as 300, and with meandering factor values equal to 1.0, 1.1, 1.15, 1.2 and 1.25. The results obtained indicate that as meandering factor increased from 1.0 to 1.25, number of generated alternative paths between the terminal pairs has increased and the demand satisfied along the paths has also increased. When the meandering factor has increased from 1.00 to 1.10, generated routes have increased from 24 to 53. It is observed that when meandering factor has increased from 1.15 to 1.25 the number of acceptable routes has increased from 53 to 61. The increase of only 8 routes indicates that the number of acceptable routes for the network converges at a meandering factor close to 1.20. Further increase in meandering factor is not likely to increase the number of acceptable routes.

By keeping other factors such as meander factor, route length as constant, different simulation experiments are conducted with cutoff total daily demand equal to 6000, 9000, 12000. Routes are generated for five different meandering factor levels ranging from 1.00 to 1.25. It is observed that as the cutoff demand level increases, the number of paths generated decreases. The paths of the accepted routes for different levels of cutoff demand are compared. The results indicate that for a particular meandering factor the paths generated at higher cutoff demand level are identical to the paths at lower cutoff demand level. However the number of accepted routes is more at lower cutoff demand levels. A suitable cutoff demand level will not accept routes, which have lower level of demand satisfaction.

7. SUMMARY AND CONCLUSIONS

This study develops a program system for dynamic scheduling of direction-oriented routes by simulating passengers flow at each stop and movement of buses along the route. The system of fixed headway operation cannot deal various problems like large variations in passenger demands, high desired frequency in certain peak periods and short different patterns of passenger arrivals at stops. This model attempts to improve the system operation of direction-oriented routes by adopting dynamic scheduling of buses.

The model is tested for the Ring road system of New Delhi. The circular bus transit system on the ring road is simulated for morning peak period from 7:30 a.m. to 10.30 a.m. Depending on the average link flow criterion, 100 buses were taken and initial time table was prepared. This is given as input to the model. The model suggests 21 additional buses. The average waiting time of passengers, average queue length, maximum queue length formed at each stop is also given as an output along with saving in waiting time at all stops because of scheduling 21 additional buses. With the initial buses taken on the network and number of terminals as the sensitivity parameters, different simulation experiments are conducted. Increase in number in buses till a saturation point improves the level of service. System performance also improves with increased number of terminals without any appreciable change in the total number of buses required for scheduling. Comparing, Dynamic scheduling with fixed scheduling the results clearly demonstrates that dynamic scheduling provides better level of service.

The parameters selected for sensitivity analysis for primary generated routes are meandering factor to be adopted for generation of routes, and the minimum demand level for primary routes. With increase in meandering factor from 1.0 to 1.25, number of generated alternative paths between the terminal pairs increases and the demand satisfied along the path also increases. But beyond a particular meandering level, paths of the accepted routes are identical and the number of generated routes will not differ much in number. This ascertains that an appropriate choice of meandering factor needs to be made. With the increase in cutoff demand level, the number of paths generated decreases. This is because some paths, which satisfy all the specified criteria of meandering factor, route length, and minimum inter terminal demand level etc., have failed in cutoff demand criterion. For a particular meandering factor, the paths generated at higher cutoff demand level are identical to the paths at lower cutoff demand level. However, the number of accepted routes is more at lower cutoff demand level. These results validate the procedure adopted for generation of routes.

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Figure 1.Flow chart of scheduling model