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Frequency of Buses Determination Model and Bus Schedule in Chennai Metro Transport for ITS Based System

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ABSTRACT: Public transport system can be made attractive in terms of quicker travel, convenience and comfort to the user. This will improve the satisfaction of transport customers. Frequency of buses for fixed period is required to provide good service at minimal cost. This paper discusses a model for determining optimal frequency of buses for a fixed period for Chennai metro transport. The objective function for this model is fixed as minimization of operating cost of buses and total waiting time cost of passengers boarding the bus subject to load factor and waiting time constraint. The objective function consists of user cost component for minimizing the total waiting time of passengers and operating cost component for minimizing the total vehicle operating cost. By determining the frequency for a fixed period, the schedule can be made flexible.

KEYWORDS: Frequency , headway, crush load capacity.

I. INTRODUCTION

The urban transportation has come under heavy strain affecting the quality of life of urban dwellers. Public transport system can be made attractive in terms of quicker travel, convenience and comfort to the user. This will increase the efficiency of each public transport made available.

A cost effective and efficient bus timetable embodies a compromise between passenger comfort and cost of service. A good match between bus supply and passenger demand occurs when bus schedules are constructed, so that the observed passenger demand is accommodated while the number of vehicles used is minimized. Transit schedulers taking into account the satisfaction and convenience of system users; appreciate the importance of scheduling with minimum waiting time that enables the passenger transfer from one route to another with minimum waiting time. Usually waiting time occurs, because of traffic, breakdown, overcrowding. During peak hours many buses are not stopping at many stops. Because of overcrowding people are struggling. Overcrowding occurs, because of insufficient bus service and inflexible scheduling.

Encouraging optimal use of existing and proposed public transport will be an effective way of achieving the desired model share between different modes .Frequency means total number of trips needed to satisfy the passenger demand during the fixed period. The operation period is divided into several sub-periods for which a specific number of trip is determined. Frequency determination plays an important role in scheduling for providing quicker travel, convenience and comfort to the user. Considering passenger demand at each stop is very important in determining the optimum frequency.

The main objective of this paper is minimization of operating cost of buses and total waiting time cost of passengers boarding the bus subject to load factor and waiting time constraint. The objective function consists of user cost component and operating cost component. The user cost component consists of minimizing the total waiting time of passengers. The operating cost component consists of minimizing the total vehicle operating cost. One way to reduce the operating cost and waiting time of passenger is determining the optimum frequency

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II. LITERATURE SURVEY

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Cedar and Wilson [6] have discussed a transit route design network model for eliminating a large number of transfer point, due to their adverse effect on the user. The objective of this model is minimizing the waiting time of passengers. In order to allow for an adequate level of bus service the schedulers face the synchronization task to ensure maximal smooth transfers involving switching passengers from one route to another with minimum waiting time. By doing so the scheduler creates an attractive transit system that generates the opportunity for increasing the number of riders.

Desilet and Rousseau [10] have discussed a model, which selects the starting time for each route from a set of possible starting time. The objective function of this model is to minimize the total penalty associated at each transfer node of the given network. The penalty function is calculated in various ways taking into account the random nature of the traveling time. Using this model, the waiting time of passengers can be reduced.

Andre de palma, Robin Lindsey [4] have discussed the circle model for creating the optimal timetable for a given number of transport vehicles on a single transit line when riders differ with respect to the times at which they prefer to travel and schedule delay cost they incur from traveling earlier or later than desired. The problem of minimizing the rider's total delay cost is formulated in continuous time and first order optimality conditions are identified. In circle model desired travel times are distributed around the clock and rescheduling of trips between day is possible.

A.Ceder,B.Golany,O.Tal [5]have discussed the problem of generating a time table for a given network of buses so as to maximize their synchronization. It attempts to maximize the number of simultaneous bus arrivals at the connection nodes of the network.Transit schedulers,taking in to account the satisfaction and convenience of the system's users,appreciate the importance of creating time table with maximal synchronization, which enables the transfer of passengers from one route to another with minimum waiting time at the transfer node. In this paper the problem is formulated as a mixed integer linear programming problem and also a heuristic algorithm is developed to solve the problem [1-5].

Z Fu has discussed computer-aided techniques to optimize the departure and arrival time windows for all passenger trains on the network. In the computer-aided train scheduling systems developed recently, the determination of passenger train departure and arrival times depends fundamentally on the experience of train schedulers. The problem of scheduling train departure and arrival time windows to minimize the total passenger inconvenience is solved firstly.

Chin and Schonfeld [8] have discussed the model of developing optimal integrated schedule for urban rail and feeder bus operation. The objective function for this train and bus scheduling model is fixed as minimization of overall cost.

Ashish Verma and S.L.Dhingra[3] have developed a model of optimal integrated schedules for urban rail and feeder bus operation. The objective function for train scheduling sub model is fixed as minimization of sum of operating costs of trains and total waiting time cost of passengers boarding the train subject to load factor and waiting time constraint where as the objective function for schedule coordination sub model is fixed as minimization of sum of total operating cost of feeder buses total transfer time cost of passengers transferring from train to feeder buses and total waiting time cost of passengers boarding enroute subject to load factor and transfer time constraint. This approach will avoid congestion and delays to a great extent.

Using this model, the waiting time of passenger and operating cost of trains can be reduced. The proposed bus scheduling model is modified from this model for the purpose of reducing the waiting time of passengers considering the demand in each stop and operating cost of buses.

III. FREQUENCY OF BUSES DETERMINATION MODEL AND BUS SCHEDULE

The proposed model is developed for the purpose of reducing the waiting time of passenger and operating cost of buses subject to load factor constraint and waiting time constraint. The objective function consists of user cost component and operating cost component. The user cost component consists of minimizing the total waiting time of passengers [11-13]. The operating cost component consists of minimizing the total vehicle operating cost. While satisfying objective, if for a given demand, the frequency of buses run on bus route is decided based only on the user cost, i.e. minimizing the waiting time, then the frequency will need to be kept as high as possible, thus requiring more

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buses. On the other hand, if the frequency for the same demand, is decided based only on the operator cost, i.e., minimizing the vehicle operating cost then the frequency will need to be kept as low as possible thus requiring fewer buses. So, the problem is to obtain the bus frequencies, which will optimize these conflicting objectives. The operating cost component consists of bus operating cost, frequency of buses, trip time for the particular route. The notations in the operating cost component are represented as

C2 = bus operating cost in Rs./min
f = frequency of buses for the particular bus route.
t = trip time for the particular bus route

The waiting time cost component consist of waiting time cost of passengers, average demand at each stop on the particular bus route, waiting time of passenger at each stop on the particular bus route. The notations in the waiting time cost component are represented as

C1 = waiting time cost in Rs./min
i = 1,2,3……….n (number of stopping)
Di = Demand at each stop i on particular bus route
Wti = Waiting time of passengers at each stop i on the particular route

The objective function is subjected to the three constraints. The first Constraint Ct1 states that the load factor on any bus route should be more than the minimum allowable load factor value Lmin for that route. The second Constraint Ct2 states that the load factor on any bus route should be less than the maximum allowable load factor value Lmax for that route [6-10]. The third Constraint Ct3 states that demand at each stop should be satisfied by the capacity of the bus. The following notations are introduced in the constraints:

Ad = Average demand of passengers on the particular bus route
Nlc = Normal load capacity of bus
Lmin = minimum allowable load factor
Lmax = maximum allowable load factor
Tdi = Total demand from source to each stop i for the particular bus route

A. Assumptions

The number of passenger boarding a bus is equal to the number of tickets sold. Passengers demand is equivalent to the average number of tickets sold.*B. Objective*

$$\text{Minimize: } \left(C1 \sum_{i=1}^{n} (Di*Wti)\right)+(C2*f*t)$$

Subject to

$$Ct1 = (Ad/(f*Nlc)) >= Lmin$$
$$Ct2 = (Ad/(f*Nlc)) <= Lmax$$
$$Ct3 = (Tdi / (f*CLC)) <= 1$$

IV. PROPOSED MODEL

The algorithm is developed for the purpose of determining the frequency of buses for a particular bus route. This algorithm was implemented in C++ language, is used to minimize the objective function and get the results. The following are the steps involved in the algorithm [14-16].

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1) Step-1: Input data required comprises of number of stopping, number of passengers boarding and alighting at each stop with in a fixed period, the bus route detail, capacity of the route, fixed period in min, Maximum and minimum headway, waiting time cost and bus operating cost, trip time.

2) Step-2: Set the upper limit and lower limit of the variable headway.

3) Step-3: Start the loop and generate different set of headway for bus routes and give the variable for minimum fitness value, a very high initial value.

4) Step-4: Check the constraint Ct1 Whether the load factor value on the particular route is more than the minimum allowable load factor value on that route. If this condition is satisfied go to step5. Otherwise go to step 3.

5)Step-5: Check the constraint Ct2 Whether the load factor on particular route is less than the maximum allowable load factor for the bus on that route. If it is not satisfied, calculate the penalty. (Use table-1)

6) Step-6: Check the constraint Ct3 whether the crush load capacity of the bus satisfies the passenger demand at each stops. If it is satisfied, waiting time of passengers at each stop is considered as average waiting time i.e, half of the headway. Then go to step9. Otherwise, go to step 7.

7) Step-7: Find the excessive demand at each stop.

Ei = Tdi - (f*CLC)

Where

Ei - Excessive demand at ith stop.

If Ei < Di

npwti = Ei

or

npwti = Di

Di = passenger Demand at ith stop

Ei = Excessive passenger demand at the stop

npwti = Number of passenger waiting at ith stop

If the excessive demand at ith stop is less than the demand at ith stop, the number of passenger waiting at ith stop is considered as excessive demand at ith stop. Otherwise number of passenger waiting at ith stop is considered as demand at ith stop.

8) Step-8: Find the extra frequency of buses needed to satisfy the passenger demand at each stop.

EFi = (npwi/CLC)

Where

EFi = Extra frequency of buses are needed at ith stop

9) Step-9: Calculate the penalty for the number of passenger waiting at ith stop.

10) Step-10: Calculate the Objective function value for the given set of headway for the bus route.

11) Step-11:. Add penalty value with the objective function to obtain the objective function value for the set of headway for bus route.

12)Step-12: Compare the fitness value with minimum fitness value obtained in previous iteration. If it is less then assign the current fitness value to the minimum fitness value variable.

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13)Step-13: Generate the next set of headway and go to step 3

14) Step-14: Iterate until all possible sets of route headways are processed for fitness value. Finally report the global minimum fitness value and the corresponding solution details.

15) Step-15: Generate the bus schedule.

TABLE I
LOAD FACTOR PENALTY

Load Factor CT2	Objective function Multiplier
1.5 – 1.59	2.5
1.6 – 1.69	3.5
1.7 – 1.79	5.5
1.8 – 1.89	6.5
1.9 – 1.99	7.5
>=2	35

The load factor values are taken from the model developed by the Ashish Verma and S.L Dhingra (Journal of Urban Planning and Development)

A. Waiting time penalty Calculation

The waiting time penalty is calculated by using the following general formula.

WTP = npw * wt * C1

Where

WTP =waiting time penalty
Npw = Number of passenger waiting
Wt = Waiting time of passenger
C1= Cost of waiting time in Rs/min

Depending upon the waiting time of passenger, the penalty of the waiting time is calculated. The following steps are involved in the waiting time calculation [17-20].

Step1. Start the loop for bus stopping.
Step2. Start the loop for the extra frequency of buses
Step3. Check the passengers are waiting at each stop. If passengers are waiting, go to step4. Otherwise, repeat this step.
Step4. Calculate the penalty for the waiting time.

If (npwi < CLC)
WTPi = npwi * (EFi * h) * C1
Or
CLC * (EFi* h) * C1
Then npwi = npwi – CLC

Where

WTPi = Waiting time penalty at each stop

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Add all the penalty value at each stop. After completed this loop, go to step 3.
Step5. Stop

V. MODEL TESTING

This model is tested on the '5 E' bus route of the Chennai Metropolitan Transport Corporation (MTC) area, a major urban center of Tamilnadu.

A. Data collection

The Data required for the frequency of buses determination are summarized below.

B. Frequency Determination

In the proposed method, practical constraints such as load factor and waiting time constraint are taken into account. Relevant data are summarized below:

1. The actual operation period is from 5A.M to 11P.M. Here selected period for determining the frequency is 8A.Mto 11A.M.Totally 3 hours.

2. The observed time for crossing one kilo meter by the bus is 3.5 minutes during the normal hours. But the MTC has fixed for crossing the one kilo meter as 3.75 minutes both
during the peak hours and normal hours. Also MTC has fixed the operating cost is Rs.30 per minute. So operating cost per minute is considered as RS.8.
3. Waiting time cost is determined from the salary of medium level people. Their monthly income is about Rs.6000.They are working 8hours per day. So waiting time cost per minute is Rs.0.42.

4. Maximum and minimum headway are fixed as 15 and 5 respectively for the peak hours. As well as Maximum and minimum headway are fixed as 25 and 10 respectively for the normal hours.

5. Normal load capacity of the bus is 50 passengers. Crush load capacity of the bus is 75 passengers.

6. Maximum allowable load factor is 1.5. (Crush load / Normal load).

7. Minimum allowable load factor is 1.

8. There are 36 stops plus source and destination in the selected '5E' route. The average number of passengers boarding and alighting at each stop for the fixed period are given in Table – II.

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TABLE II
DEMAND AT EACH STOP IN '5E' ROUTE DURING 3 HOURS

stop	Boarding	Alighting	stop	Boarding	Alighting
1	725	-	20	94	67
2	15	5	21	205	174
3	40	8	22	108	418
4	94	23	23	244	174
5	220	48	24	89	65
6	174	20	25	250	99
7	114	95	26	100	48
8	215	8	27	118	84
9	105	75	28	68	77
10	75	60	29	96	56
11	126	350	30	112	145
12	263	174	31	75	215
13	165	340	32	65	193
14	125	135	33	95	143
15	162	89	34	21	150
16	182	129	35	7	110
17	115	226	36	19	89
18	211	56	37	6	677
19	110	65	38	-	118

The bus scheduling model is developed to obtain the optimal frequency for the particular bus route. This is done to maintain a minimum acceptable point of view and also to maintain the load factor in the bus to be within the acceptable comfort level of the users in the case study area. With the input of these parameters, the algorithm was run for obtaining the bus frequencies. This model is implemented using C#. Net.

C. Output for the frequency of buses determination and bus schedule

The Headway for route '5E' is computed as 9 min. The Load factor value on this route is computed as 1.29 min.
With these values the program was run and the optimum frequency is obtained as 20. Thus in order to maintain the headway of 9 min, the total number of buses required to satisfy the passenger demand in '5E' route is 20. Maximum allowable load factor value and minimum allowable load factor value are 1.5 and 1 respectively. The current load factor

value on this '5E' route is greater than the minimum allowable load factor value and less than the maximum allowable load factor value. So, by providing 20 buses, passenger demand is satisfied. There is no waiting time of passengers and operating cost is also less. Waiting time cost is Rs 8406.30. Operating cost of buses is Rs.11, 520.The calculation of waiting time cost in proposed is shown in TableIII.

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TABLE III
WAITING TIME COST FOR THE PROPOSED METHOD

S	Di	Tdi	Ct1	Ei (Tdi-(f*Clc)	Npwti	Awt In min	Wci in Rs	P in Rs	Twci in Rs (P+Wci)
				-					
1	725	725	0.48	-	-	4.5	1370.25	-	1370.25
2	15	735	0.49	-	-	4.5	28.35	-	28.35
3	40	767	0.51	-	-	4.5	75.6	-	75.6
4	94	838	0.55	-	-	4.5	177.66	-	177.66
5	220	1010	0.67	-	-	4.5	415.8	-	415.8
6	174	1164	0.776	-	-	4.5	328.86	-	328.86
7	114	1183	0.78	-	-	4.5	406.35	-	406.35
8	215	1390	0.93	-	-	4.5	198.45	-	198.45
9	105	1420	0.94	-	-	4.5	220.5	-	220.5
10	75	1435	0.95	-	-	4.5	141.75	-	141.75
11	126	1211	0.81	-	-	4.5	238.14	-	238.14
12	263	1300	0.86	-	-	4.5	407.07	-	407.07
13	165	1125	0.75	-	-	4.5	311.85	-	311.85
14	125	1115	0.74	-	-	4.5	236.25	-	236.25
15	162	1188	0.79	-	-	4.5	306.18	-	306.18
16	182	1241	0.83	-	-	4.5	343.98	-	343.98
17	115	1130	0.75	-	-	4.5	217.35	-	217.35
18	211	1285	0.86	-	-	4.5	398.79	-	398.79
19	110	1330	0.89	-	-	4.5	207.9	-	207.9
20	94	1357	0.9	-	-	4.5	177.66	-	177.66
21	205	1388	0.93	-	-	4.5	387.45	-	387.45
22	108	1078	0.72	-	-	4.5	204.12	-	204.12
23	244	1148	0.71	-	-	4.5	461.16	-	461.16
24	89	1172	0.78	-	-	4.5	168.21	-	168.21
25	250	1323	0.88	-	-	4.5	472.5	-	472.5
26	100	1375	0.92	-	-	4.5	189	-	189
27	118	1409	0.94	-	-	4.5	223	-	223
28	68	1400	0.93	-	-	4.5	128.5	-	128.5
29	96	1440	0.96	-	-	4.5	181.44	-	181.44
30	112	1407	0.94	-	-	4.5	211.68	-	211.68
31	75	1267	0.85	-	-	4.5	141.75	-	141.75
32	65	1139	0.76	-	-	4.5	122.85	-	122.85
33	95	1091	0.73	-	-	4.5	179.55	-	179.55
34	21	962	0.64	-	-	4.5	39.69	-	39.69
35	7	859	0.572	-	-	4.5	13.23	-	13.23
36	19	789	0.53	-	-	4.5	35.9	-	35.9
37	6	118	0.1	-	-	4.5	11.34	-	11.34
38	-	-	-		-	-	12.6	-	12.6
							-		-

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TABLE IV
WAITING TIME COST FOR THE EXISTING METHOD

S	Di	Tdi	Ct3	Ei = (Tdi - (f*Clc)	Npwti	Awt In min	Wci in Rs	P in Rs	Twci in Rs (P+Wci)
1	725	725	0.69			6.25	1903.1		1903.12
2	15	735	0.7	-	-	6.25	39.37	-	39.37
3	40	767	0.73	-	-	6.25	105	-	105
4	94	838	0.79	-	-	6.25	246.75	-	246.75
5	220	1010	0.96	-	-	6.25	577.5	-	577.5
6	174	1164	1.1	-	-	6.25	456.75	-	456.75
7	114	1183	1.11	114	144	6.25	299.25	231	530.25
8	215	1390	1.13	133	114	6.25	564.37	336	900.37
9	105	1420	1.323	340	105	6.25	275.63	2205	496.13
10	75	1435	1.35	370	75	6.25	196.20	708.75	904.95
11	126	1211	1.37	385	126	6.25	330.75	393.75	724.5
12	263	1300	1.15	161	250	6.25	690.37	561.75	1252.12
13	165	1125	1.24	250	75	6.25	433.61	1653.75	2087.46
14	125	1115	1.1	75	126	6.25	328.13	26.25	354.38
15	162	1188	1.13	65	250	6.25	425.25	357	782.25
16	182	1241	1.18	138	75	6.25	477.75	876.75	1354
17	115	1130	1.07	191	65	6.25	301.80	52.5	354.3
18	211	1285	1.2	80	162	6.25	553.87	1211.25	1765.12
19	110	1330	1.3	235	182	6.25	288.7	761.25	1049
20	94	1357	1.32	280	80	6.25	246.75	593.25	840
21	205	1388	1.02	307	211	6.25	538.12	2047.5	2585.62
22	108	1078	1.09	338	110	6.25	283.5	147	430.5
23	244	1148	1.116	28	94	6.25	640.5	273	913.5
24	89	1172	1.26	98	205	6.25	233.6	2045.5	2279.1
25	250	1323	1.3	122	28	6.25	656.25	656.25	1312.5
26	100	1375	1.34	273	98	6.25	262.5	845.25	1107.75
27	118	1409	1.33	325	89	6.25	309.75	357	666.75
28	68	1400	1.37	359	250	6.25	178.5	614.25	792.75
29	96	1440	1.34	350	100	6.25	252	782.25	1040.25
30	112	1407	1.2	390	118	6.25	294	393.75	687.75
31	75	1267	1.08	357	68	6.25	196.88	99.75	296.63
32	65	1139	1.03	217	96	6.25	170.63	52.5	221.13
33	95	1091	0.92	89	65	6.25	249.38	-	249.38
34	21	962	0.82	-	-	6.25	55.125	-	55.125
35	7	859	0.76	-	-	6.25	18.375	-	18.375
36	19	789	0.112	-	-	6.25	49.85	-	49.85
37	6	118	0.1	-	-	6.25	15.75	-	15.75
38					-				

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In order to check the effectiveness of the proposed method, the waiting time cost is incurred in the existing method of bus operation is computed and given in table IV.

VI. COST COMPARISON

The Chennai MTC is providing 14 buses to satisfy the existing demand for the fixed period of three hours. Headway is 12.5 minute. Here cost comparison is made for the purpose of determining the benefit of the proposed method. To operate 14 buses under the existing method and to operate 20 buses under proposed method, the waiting time cost, operating cost and total cost are computed and given in table V.

TABLE V
COST COMPARISON

	Proposed method	Existing System
Headway	9 min	12.5 min
Frequency	20(bus)	14 (bus)
Waiting Time Cost	Rs 9140	Rs 28,767.63
Operating Cost	Rs 13,120	Rs 8,960
Total Cost	Rs 22,260	Rs 37,727

In existing system, When MTC will run 14 buses, operating cost of buses is less. But waiting time cost is high. It indicates more passengers are waiting because of insufficient bus service and ineffective planning. But in proposed method operating cost of buses is high. Waiting time cost is less while comparing with existing system. Also total cost is less in the proposed method than in the existing method. So, Using the frequency determined by the bus scheduling algorithm, passenger demand is satisfied and total cost is reduced.

VII. CONCLUSIONS

This study deals with the determination of frequency for the bus operation. It is an important issue for the bus transit system and substantial savings can be made without significantly reducing the service level. This present study is only limited to the frequency determination at the city level. It appears that overcrowding of buses is not only caused by limited buses, but also by ineffective planning The bus scheduling model is able to identify the frequency of buses for the bus operation by optimizing the waiting time and vehicle operating cost subject to load factor and waiting time constraint. In this model better results in terms of minimized objective function value are obtained.

VIII. LIMITATIONS

1. Every time trip time will change based on the delay. Delay can be avoided.
2. Wide variation in results is seen due to slight change in any penalty. Therefore appropriate penalties should be decided as per their relative importance for better and acceptable results.

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IX. SCOPE FOR THE FUTURE STUDY

For the future work, the delay can be identified and controlled by using the decision support system.

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