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Research Article

Optimization in Scheduling of Bus Commuter Services

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Abstract

This paper deals with timetabling process of a commuter bus services. The timetabling of commuter bus services in metropolitan cities is very complex one. As the numbers of buses are very much and service to be provided to the customer is crucial parameter, the main focus for the scheduling of buses can be "BEST" services offered to the customer in terms of minimization of Total Average Waiting Time (TAWT) of the customer at the various stations. A case study of VTCOS city bus services of Bhavnagar is taken here to demonstrate, how to achieve the goal with all the available current resources & improve the scheduling system by reducing the TAWT of the customer. ***As there are so many constraints when schedule is to be prepared, we have developed an algorithm to decide the best sequence and starting time of the buses during peak hour (when demand is highest) period and constraint propagation system to decide the running time of the buses on the specified route between stations with arrival time.*** *The technique described here will be very much useful when resources are limited and requirements are heavy for the different kinds of commuter services (commuter train, transport and trams). The fundamental issue covered here is to schedule the routing of the buses in the city and the algorithm described here may help to schedule other kind of transportation services too.*

Keywords: *TAWT, Waiting time, City bus services, VTCOS, Scheduling of commuter services, Bhavnagar*

1. Introduction

India has one of the largest road networks in the world. The country's total length was 20,65,209km in 1991-1992. Outlay for road development under the seventh plan for the central sector was Rs. 1019.75 cr., for the state sector Rs. 3666.98 cr. and for union territories Rs. 513.31 cr. During seventh plan Rs. 6179.75 cr. was spent on road development. For the eighth five year plan an outlay of Rs. 2600 cr. and Rs. 10610 cr. was approved for state and central sector roads.

Looking at the scenario it could be seen that benefits of transportation to the economy are enormous. Transportation infrastructure is a significant part of the nation's wealth.

2. Commuter service scheduling

Commuter service is a heart of any city because it helps maintain the vitality of our major cities central business districts. It connects people to their jobs and rural areas. It relieves traffic congestion and improves business productivity with less energy consumption.

The above benefits can be achieved only if the commuter services are well planned and effectively scheduled. More over the scheduling of commuter service contains several parameters to be control which can be categorized in form of constraints.

2.1 Constraints

Head way: It imposes time restriction between two consecutive buses on the same route.

Slack: It has to be provided in the span of small time period for cushioning effect

Turnaround time: It is a turnaround time at the end of route of particular bus

Demand: It a commitment to the number of services to the destination during particular time interval.

Linking Constraint: It imposes a constraint as linking between buses at the end of their particular trip.

Man power allocation: Allocation of man power for the planned trips

The objective for the effective and efficient schedule can be formed with an optimization of resource utilization and minimum amount of customer waiting time.

3. Overview of VTCOS bus services

VTCOS (Vallbhipur Transport Cooperative Society), with its members as private transport operators was formed in 1997. The transport utility of the Bhavnagar

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city was formerly handed over to the society on 19th July 2001. In the first phase 10 buses were gradually introduced, besides the 14 buses running then. Earning rose by 10 % a day for the initial month which greatly enthused operators. Moreover far flung areas of the city, which remained greatly deprived of cheaper transportation, now enjoy bus trips at every 20-30 minutes time interval. The adjoining villages too have benefited substantially as city buses have reached their doorsteps providing greater connectivity to the urban areas. About 50000-60000 people are using this facility every day. The services are provided from 6.00 am to 10 pm. The services are divided into two slots like 6.00 am – 2.00pm and 2.00pm – 10 pm. All the patterns (routes) are defined in annexure A and frequency of that pattern (route) is given in annexure B. It has mainly 14 routes that covers all the major areas of the Bhavnagar city by 32 buses. It has been identified that the peak hours are spreaded from 8.00pm – 11.am and 5.30pm – 8.30pm. During peak hour demand of buses are heavy and satisfying the needs of the customer is critical.

This paper focuses on the objective of satisfying the customer need in terms of minimization of their waiting time.

4. Approach to timetabling process

From the existing timetable for peak hour period there are 65 buses on 14 routes needed. This paper contains study of peak hour period and rescheduling of buses in the consideration of minimization of customer waiting time.

Here, some useful parameters are defined which will be used in the algorithm proposed ahead.

Sequence of pattern

There are 65 buses during peak hour time period 8am – 11 am, the order of the buses that are going to run within that time period is called as sequence of pattern
Arrival rate of customer

λ_k is the number of customers arriving at particular station k per unit of time period (per minute) with uniform rate.

Average waiting time of the customers

The average total number of customers waiting for some time period, to get in to the bus at particular station k. i.e. the time of waiting of the customers between every two consecutive buses halt at the station k.

Total Average total waiting time of the customers

It is a total sum of average waiting time of customers over total number of stations.

As the number of buses and its pattern are available as input, the aim is to generate a good feasible sequence of patterns. The objective here is to minimize the total average waiting time of the customers. An algorithm is developed here to generate the sequence of pattern, which can satisfy the said objective. Once sequence is generated then calculation of tentative departure times can be carried out for all buses from the respective destinations as per nature of pattern (here demand, slack and headway constraints are considered). Using runtime of buses the arrival and departure time of buses can be calculated easily, which leads to clash free timetable. Thus here comparison between existing and proposed schedule can be made for said objective of minimization of total customer waiting time.

4.1 Minimization of waiting time of the customer

As defined earlier rate of customers arriving at station k is λ_k. now the total number of customers arriving at the station can be calculated as below.

The total number of customers at station k,

$$\beta_k = \Sigma\ \lambda_k * (t_{i+1,k} - t_{ik}) \qquad 4.1.1$$

where t_{ik} and $t_{i+1,k}$ are timings of two consecutive buses As the arrival rate of customer is uniform.(see figure 1)

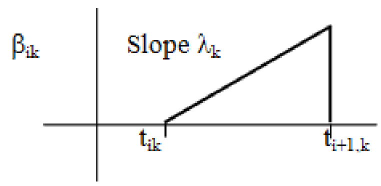

Figure 1

From the figure 1 above it can be seen that the total number of customers are waiting for $t_{i+1,k}$ - t_{ik} time period at station k. But each customer may not have to wait for the same time period so, average time period is to be taken in to consideration for which customers are waiting at particular station k. (that is 1/2 of $t_{i+1,k}$ - t_{ik}.)

The average waiting time at station k for the customers can be defined as under,

Average waiting time of the customers at station k = total number of customers arrived at station k * average time period of which they are waiting.

$$W_k = \Sigma\ 1/2*\lambda_k* (t_{i+1,k} - t_{ik})^2\ \forall I \qquad 4.1.2$$

TAWT (Total Average Waiting Time) of the customers

$$W = \Sigma\ \Sigma\ 1/2*\lambda_k* (t_{i+1,k} - t_{ik})^2\ \forall i\ \forall k \qquad 4.1.3$$

Let's examine the two sequences of patterns, for average waiting time at station k.

There are total 3 buses stops at station k, and its departure times are t_{ik}, $t_{i+1,k}$ and $t_{i+2,k}$

Case I

The buses are halting at station k by approximately equal time duration (see figure 2, a=b).

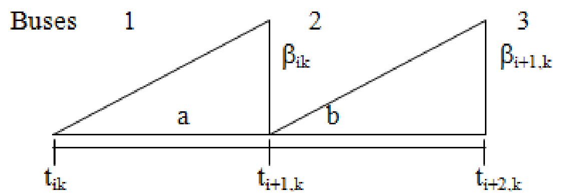

Figure 2

Case II

The buses are halting at station k by unequal time period (see figure 3, a≠ b)

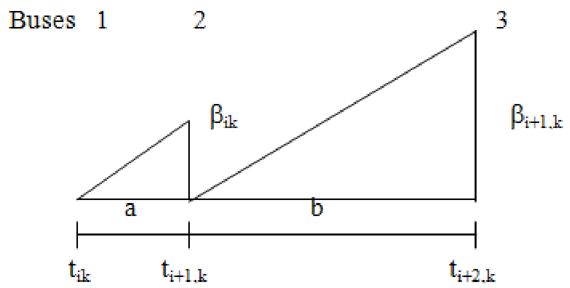

Figure 3

If $t_{i+1,k} = t_{ik} + a$ and $t_{i+2,k} = t_{ik} + b$

So, $t_{i+2,k} = t_{ik} + a + b$

here a, b are fixed as total time period is remain same.

$W_k = 1/2*\lambda_k* (t_{i+1,k} - t_{ik})^2 \ \forall\ i$

$= 1/2*\lambda_k*[(t_{i+1,k} - t_{ik})^2 + (t_{i+2,k} - t_{i+1,k})^2]$

$= 1/2*\lambda_k*[a^2 + b^2]$

The average waiting can be minimized if a = b

From the above example it can be evaluated that the TAWT at station k for the case I is less then the waiting time for the case II. More over customers will be more satisfied because of average rush in case I, while in II case during the time interval of $(t_{i+2,k} - t_{i+1,k})$ large number of customers are gathered at station k and due to heavy rush they will be unhappy. As a result if trains are distributed by same time interval, then the TAWT will be less as well as more customers' satisfaction can be achieved. For the different set of sequence of patterns the TAWT of the customers will be different. For example if buses having same type of pattern are assigned together along a sequence then TAWT will be higher. On the other case if buses having same type of pattern are uniformly distributed along a sequence then the TAWT will be lower.

From the above discussion it implies that the waiting time is dependent on nature of sequence of the patterns, i.e. the waiting time can be calculated if we have a sequence of patterns and departure times of the buses at particular station. One way is to examine all the possible number of sequence of patterns but it will take more time to get the best sequence out of them. So, some initial sequence can be picked up and iterate such that it converges to the some local minimum of TAWT from the set of total possible sequence of patterns. But as the parameters like, departure times at each station, detail information of patterns (where the bus is halting) should be known to us initially and the TAWT of the customers varies with the square difference between the departure timings of two consecutive buses, which stops at station k.

As we know that the λ_k constant and W_k is dependent on the nature of sequence of patterns, from the two cases described above if buses halt at particular station at some equal time period then the TAWT will be less. Similarly pattern of buses is nothing but the halting information of the buses at different stations and the service level. So, the pattern should be spread out on the time span as uniform as possible.

Here a heuristic is proposed to find out the good feasible sequence. It just looks at the pattern followed by the different buses; the departure times at each station need not to be considered.

4.1.2 Heuristic Approach

Here are some criteria to generate good feasible sequence.

1. The same patterns should be spread out in the sequence because the waiting time can be reduced to a significant amount.
2. Demand of the customer should be satisfied.

Here the method is proposed keeping first three criteria described above.

Assumptions

1. All the patterns are independent of each other means there is no relation between any pattern considering demand and service level.
2. Buses and manpower is available as per the requirement.
3. Even though source and destination of certain route are same, demand of customer is treated as independent.

To describe the procedure we have taken 10 buses following four patterns.

Table 1

Pattern Number	No. of Services (freq)
1	3
3	1
4	4
5	2

Number of buses are to be taken as input in decreasing order of their frequencies because from the method suggested below it can be seen that score with respect to particular bus is higher at the ends of the sequence. So, if the scores with respect to particular bus is arranged in descending order of it's value then each bus has an good opportunity to prove its existence in the sequence of patterns as best as possible (it will be distributed uniformly).

From the table it can be seen that there are higher scores at the ends so if that are arranged in descending order then all the patterns which are clustered together will be distributed alternately, and further iteration gives a uniform distribution of the patterns.

Following sequence of pattern is taken as input.

4 4 4 4 1 1 1 5 5 3

Step 1: Input the sequence of pattern in descending order with respect to the frequency of patterns as above.
Pattern number, X(i) = j
Where i = index of the bus, from 1 to n (total number of buses)
j = index of the pattern, from 1 to m (total number of patterns)

Step 2: Compare the different patterns with other patterns in the sequence,

```
for i = 1 to n    Where, n = total no., of trains
for k  = 1 to n
   if X(i) = X(k) (checking of pattern type)
score  = mode( k -i ) * w ( w is the weightage factor that is 1 if the same pattern and 2 if the pattern is different )
  Else
       score  = mode(k-i) * 2
```

for each train i with particular pattern j we will have a score.

Step 3: Find the score of each train i having particular pattern j. Arrange them in descending order. Simultaneously arrange corresponding train with particular pattern to its score.

Step 4: Now another set of sequence is obtained. Again find out the score of a new sequence of pattern with the method suggested above.

Step 5: If the score for the previous sequence of pattern is less than new sequence of pattern generated then go to step 6, otherwise go to step 2 with new order of sequence of patterns.

Step 6: Print the previous sequence of patterns (which can be a local minima of the total possible number of sequences).

Step 7: Any interchanges if required then apply

Tabulation for the first raw is shown as below

Table 2

Service number	1	2	3	4	5	6	7	8	9	10
Pattern	4	4	4	4	1	1	1	5	5	3
Weightage	1	1	1	1	2	2	2	2	2	2
Score	(1-1)*1	(2-1)*1	(3-1)*1	(4-1)*1	(5-1)*2	(6-1)*2	(7-1)*2	(8-1)*2	(9-1)*2	(10-1)*2
	=0	=1	=2	=3	=4	=10	=12	=14	=16	=18

From the method described above the following table 3can be obtained

Table 3

busno		1	2	3	4	5	6	7	8	9	10	**Total**
	pat_ no	4	4	4	4	1	1	1	5	5	3	
1	4	0	1	2	3	8	10	12	14	16	18	84
2	4	1	0	1	2	6	8	10	12	14	16	70
3	4	2	1	0	1	4	6	8	10	12	14	58
4	4	3	2	1	0	2	4	6	8	10	12	48
5	1	8	6	4	2	0	1	2	6	8	10	47
6	1	10	8	6	4	1	0	1	4	6	8	48
7	1	12	10	8	6	2	1	0	2	4	6	51
8	5	14	12	10	8	6	4	2	0	1	4	61
9	5	16	14	12	10	8	6	4	1	0	2	73
10	3	18	16	14	12	10	8	6	4	2	0	90
Total												630

Now arrange the score with respect to each train in to descending order. That will give a new sequence 3 4 5 4 5 4 1 4 1 1 with score 604, and do the same procedure until minimum score is obtained, that is called as local optima from the set of total number of the sequence of patterns. The procedure is shown next,

	Sequence of patterns										**Score**
Input	4	4	4	4	1	1	1	5	5	3	630
1st iteration	3	4	5	4	5	4	1	4	1	1	604
2nd iteration	3	1	1	4	5	4	1	5	4	4	592
3rd iteration	**3**	**4**	**1**	**4**	**5**	**1**	**5**	**1**	**4**	**4**	**578**
4th iteration	3	4	4	4	1	1	5	5	1	4	592

From the above sequences it can be seen that at 3rd iteration good feasible sequence has obtained. Now compare all the sequences with respect to TAWT (using eq 4.1.3) in hours.

	Sequence of patterns										TAWT
1st iteration	3	4	5	4	5	4	1	4	1	1	1191
2nd iteration	3	1	1	4	5	4	1	5	4	4	971
3rd iteration	3	4	1	4	5	1	5	1	4	4	819
4th iteration	3	4	4	4	1	1	5	5	1	4	853

From the above calculations of TAWT of the customers it implies that the sequence which has lower score also has lower waiting time.

Advantages

It gives local optima from the set of all possible sequences of patterns. The computation time is very less. Any interchanges can be made very easily if required any (i.e. during second phase if any unfeasibility found then patterns can be interchanged in the sequence).

Disadvantage

It doesn't give the sequence of pattern with least score among all possible number of sequences of patterns.

Some other approaches like simulated annealing or genetic algorithm may give better solution.

5. Implementation

From the sample calculation of 4 patterns and 10 buses it has been proved that TAWT can be reduced by the heuristic approach. Here the implementation of is carried out further on 65 buses during peak hour period with following patterns

Table 4

Pattern_no (route)	No of Services
1	2
2	3
3	6
4	7
5	3
7	4
8	7
9	5
10a	7
10b	2
11	5
12	3
12a	4
14a	7

Using the algorithm explain earlier Input the above sequence of 65 buses according to their patterns in descending order

Input

Table 5

14	14	14	14	14	14	14	9	9	9
9	9	9	9	7	7	7	7	7	7
7	4	4	4	4	4	4	4	3	3
3	3	3	3	11	11	11	11	11	8
8	8	8	8	13	13	13	13	6	6
6	6	12	12	12	5	5	5	2	2
2	10	10	1	1					

After various iterations output of the 65 buses during peak hour period is obtained as below

Output

Table 6

1	7	9	9	4	14	14	7	3	9
9	7	4	11	3	13	7	2	3	8
12	7	8	11	6	14	8	5	13	14
1	12	5	2	10	4	14	11	9	13
7	5	6	4	7	6	4	3	8	9
10	14	3	4	11	12	3	13	6	2
8	11	4	9	14					

Based on the sequence the timings of buses can be evaluated as below

Existing Timetable

Table 7

Departure time of buses							
1	8.40	10.00					
2	8.10	9.25	10.40				
3	8.15	8.45	9.15	9.45	10.15	10.45	
4	8.00	8.30	9.00	9.30	10.00	10.30	11.00
5	8.30	9.30	10.30				
7	8.00	9.00	10.00	11.00			
8	8.00	8.30	9.00	9.30	10.00	10.30	
9	8.15	8.45	9.30	10.00	10.40		
10a	8.00	8.30	9.00	9.30	10.00	10.20	10.55
10b	9.20	10.45					
11	8.10	9.10	10.00	10.30	11.00		
12	8.30	9.45	11.00				
12a	8.40	9.10	10.00	10.40			
14a	8.30	9.00	9.15	9.45	10.15	10.30	11.00

New Timetable

Table 8

Departure time of buses							
1	8.00	9.22					
2	8.47	9.30	10.43				
3	8.21	8.38	8.50	10.08	10.22	10.33	
4	8.10	8.33	9.35	9.56	10.05	10.25	10.53
5	9.14	9.27	9.50				
7	9.06	9.53	10.03	10.40			
8	8.02	8.18	8.30	8.45	9.47	10.00	
9	8.52	9.00	9.11	10.11	10.46		
10a	8.05	8.07	8.23	8.27	9.42	10.14	10.57
10b	9.33	10.16					
11	8.35	9.03	9.40	10.27	10.50		
12	8.55	9.25	10.30				
12a	8.42	9.17	9.45	10.36			
14a	8.13	8.16	9.08	9.20	9.38	10.20	11.00

For the purpose of calculation of TAWT, details of λ_k (number of customer waiting at each stop for each pattern) is given in the following table

Table 9

λ_k for different patterns															
No of Stops		1	2	3	4	5	7	8	9	10a	10b	11	12	12a	14
	1	12	2	10	10	6	14	8	14	12	15	13	8	12	12
	2	10	3	5	5	3	10	5	10	8	9	7	5	5	8
	3	15	5	3	4	3	6	4	5	7	12	6	3	3	5
	4	4	7	4	4	4	8	4	7	5	10	3	3	3	6
	5	3	2	5	6	2	5	3	3	7	9	6	2	8	3
	6	3	3	3	7		5	2	3	9	7	4	3	2	2
	7	6	8				6	1	6	7	5	4		3	5
	8	2	5				4		2	7	5	3		1	3
	9	2					3		4	5	4	4		3	2
	10	3					4		2	4	3	5		2	
	11	4								6	3	4		1	
	12	3								4	4	3			
	13	5								3	3	3			
	14	5								2	2				
	15	7								2	2				
	16	5								1	4				
	17	4									3				
	18	7									3				

By using the equation 4.1.3 for all the 14 routes and 65 buses during peak hour period the TAWT has been calculated as below
TAWT for existing system = 1198hrs
TAWT for new timetable = 1083 hrs
Thus it is observed that the average waiting time of customer is reduced

Conclusion

Here we have proposed a method to minimize the TAWT of the customer with the consideration of several constraints. Using the algorithm one can make schedule of commuter services very effectively and efficiently.

This algorithm can be extended to rail, freight an air scheduling also.

In future, the organization can think upon linking of various patterns so the same number of buses can provide more number of services. It is advantageous that algorithm can be easily coded and organization can make up the schedule very easily in case of any disturbance occurs.

Few of the parameters are not considered here like liking and manpower allocation, which can be accommodated by using proper OR models.

VTCOS is taken a case problem, the tools provided here for generation of schedule can be automatically extended on other system with small changes depending upon resource availability.

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Existing schedule of VTCOS services.

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Appendix A

Pattern No	Route Description
1	Kalvibid (Circular)
2	Kalvibid (Circular via waghavadi)
3	Bharat nagar (via Subhashnagar)
4	Bharat nagar (via Ghogha circle)
5	Anand nagar
7	Vartej (via Chitra)
8	Kumbharwada (via Chitra)
9	Nari village ((via Chitra)
10a	S.S. Engg College, Valukad village (via Sanskar mandal)
10b	Sidsar, Valukad village (via Chitra)
11	Avania, Malnka village
12	Bharat nagar (via Waghawadi)
13	Budhel (via Rammantra mandir)
14	Karmachari nagar

Appendix B

Frequency of buses during peak hour period

Pattern No	Run Time	No of Services
1	60	2
2	55	3
3	35	6
4	30	7
5	35	3
7	45	4
8	40	7
9	45	5
10a	40	7
10b	30	2
11	35	5
12	25	3
13	35	4
14	25	7