Scheduling of Bus Fleet Departure Time Based on Mathematical Model of Number of Bus Stops for Municipality Bus Organization

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Abstract**—**Operating Urban Bus Transit System is a phenomenon that has a major role in transporting passengers in cities. There are many factors involved in planning and operating an Urban Bus Transit System, one of which is selecting optimized number of stops and scheduling of bus fleet departure. In this paper, we tried to introduce desirable methodology to select number of stops and schedule properly. Selecting the right number of stops causes convenience in accessibility and reduction in travel time and finally increase in public preference of this transportation mode. The achieved results revealed that number of stops must reduce from 33 to 25. Also according to scheduling and conducted economic analysis, the number of buses must decrease from 17 to 11 to have the most appropriate status for the Bus Organization.

Keywords**—**Number of optimized stops, organizing bus system, scheduling, urban transit.

I. Introduction

DUE to lack of considering of coordinating and planning departure time for urban bus system, this mode of transportation is not very popular among people and number of attracted trips of this transportation mode is fewer than expected [1]. Hence, this is essential to reconsider the reliability of this system from passengers' and users' vision. Moreover, number of optimized stops and scheduling of lines according to the status is reviewed and the most appropriate method is introduced [2], [3]. After designing the network, scheduling of bus lines is considered during which a motion schedule for every line is defined according to other operating indices. The output of this stage schedules the departure and arrival time of buses at each stop in every line [4], [5]. In the following, some of the studies carried out are reviewed.

II. Literature Review

Gleason spent some time to locate the bus stops with the minimum number of stops and recommended an alternative model that minimized the traveled distance by passengers [6]. Also Ceder et al. presented a model to minimize the number of bus stops. They considered the terms that none of public transportation users can not start less than a certain distance from a bus stop [8]. Reilly carried out a research about criteria and standards of distances between bus stops in Europe and The United States, and concluded that in European urban areas, two or three stops in every kilometer and in American Urban areas four to six stops are appropriate [7]. Ibeas presented a model for locating and determining the distances between stops that minimized the general cost of all transportation systems [9]. Vanitchakornpong et al. suggested a bus fleet planning model with some stops and line changing operation, to solve this problem; they proposed a local investigation method [10]. Kim et al. conducted a study on determination of optimal operating frequency and presented a timetable based on start and finish points using microscopic models, demand responsive, travel time responsive and their non-microscopic models for critical area planning [12]. Ceder presented a heuristic algorithm based on deficiency function theory for solving multi-vehicle scheduling problem [11]. Wei et al. presented more realistic models for solving schedule planning problem, which was for inaccurate and probable travel time [16].

Ming et al. investigated planning scheduling bus problem for some specific travel times [13]. Wagale et al. optimized the bus planning process, and they presented and developed a schedule for bus departures. On this direction, time information including dispatch time (departure time) and arrival time, schedule based on line and also buses' travel costs are used [15]. Shuia et al. presented a colony selection algorithm based on vehicle timing method for scheduling urban buses [14].

The scope of this research is line number two of Qazvin Municipality Bus Organization. This line is 15.3 km, which is the busiest bus line in Qazvin. It passes through shopping areas, market and historical parts of the city. This line has 17 active buses serving 18,133 passengers daily.

III. Methodology

The methodology of this research is divided into two categories. In the first one, number of optimized stops in the studied route is determined while in the second one, building and scheduling of Bus Fleet Departure is carried out. In this paper, MATLAB software is used in order to simplify the calculation and to increase the accuracy in replications.

Tirchini suggested a model to determine the number of stops, the objective function of which minimizes the total cost as [17]:

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$$C = c.f.\left(\frac{L}{v_0}+\beta\frac{N}{f}+St_s\right)+ P_a\frac{L}{2v_wS}N+ P_w\frac{1}{2f}N+ p_v\frac{l}{L}\left(\frac{L}{v_0}+\beta\frac{N}{f}+St_s\right)N \qquad (1)$$

N: Passenger Demand (passenger/hr); f: Number of Buses; S: Number of Stops; c: Operation Cost of each Cycle (dollar /hr); V_0: Bus speed (Km/h); p_a: Accessibility Cost (dollar/hour); p_W: Waiting Cost (dollar/hour); p_V: Riding Cost in vehicle (dollar/hour); υ_w: Passenger Speed ((km/h); l: Average Speed (km/h); L: Travel Distance (km); t_s: Delay time due to deceleration and acceleration, Queue time, opening and closing door time (hour); and β: Average time of embark and disembark for each passenger (hour/passenger). Then if this equation is solved to minimize the total cost:

$$S^* = \sqrt{\frac{P_aLN}{2v_wt_s\left(cf+P_v\frac{l}{L}N\right)}} \qquad (2)$$

S^*: Number of Optimized Stops. Now if (f) is constant:

$$N\rightarrow\infty \Rightarrow S^* \overset{=}{\rightarrow} \sqrt{\frac{P_aL}{2v_wt_sP_v\frac{l}{L}}} \qquad (3)$$

In case the magnitude to passenger demand is changed (f=aN):

$$S^* = \sqrt{\frac{P_aL}{2v_wt_s\left(ca+P_v\frac{l}{L}\right)}} \qquad (4)$$

IV. Results and Discussions

As it is shown with the increase in path and accessibility cost, number of optimized stops increases. In addition, with the increase in passenger speed, delay time, riding cost and number of stops decrease. According to Table I, if the number of fleet increases, the number of stops decreases.

Results of this model and relocation of stops have been indicated in Fig. 1. Table II represents the economic justification in terms of fuel consumption.

In each step, required information has been gathered by surveying team and with coordination of bus organization. In the following, by selecting representative side lines, the service periods have been divided into smaller parts. Frequency and departure interval, rest time, length of cycle and number of required buses are determined to have the start point and checkpoints. After determining checkpoints according to obtained statistics, travel time between points for different periods is achieved; their values are presented in Table II.

TABLE I
Results of Optimizing Number of Stops Based on Passengers' Preference in Public Transportation

	Number of Buses			
	constant	14	16	18
Number of stops	24.43	24.15	24.1	24.08

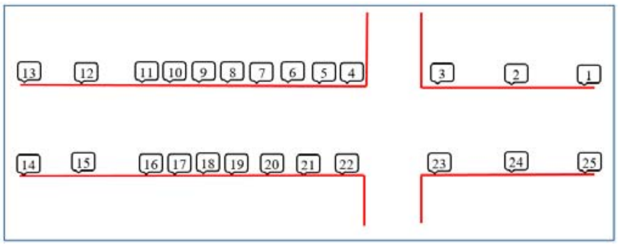

Fig. 1 The new location of stops after optimization

According to start point and travel time matrix, determinative headway, all departure times and arriving time of buses to the checkpoints are determined, thus planning is complete. In order to simplify the control, supervision and management of line, summary chart of departures in every period is given in Table II. Summary of departure schedule, number of departures in each period is shown, and in terms of flexibility of scheduling, more appropriate control and management for each line is given. Its table also is given in longer periods for more than 10 departures (Table III). The number of departures for the return path is the same number

TABLE II
Travel Time for Every Direction in Different Hours of Day between Checkpoints

hour	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21
Average travel time 1-5	12:30	12:30	12:30	18:00	18:00	18:00	18:00	15:00	15:00	15:00	18:00	18:00	12:30	12:30
Average travel time 5-8	08:30	08:30	08:30	12:30	12:30	12:30	12:30	08:30	08:30	08:30	12:30	12:30	08:30	08:30
Average travel time 8-11	08:30	08:30	08:30	13:00	13:00	13:00	13:00	09:30	09:30	09:30	13:00	13:00	08:30	08:30
Average travel time 11-13	11:30	11:30	11:30	15:00	15:00	15:00	15:00	11:00	11:00	11:00	15:00	15:00	11:30	11:30
One-way travel time	41:00	41:00	41:00	58:30	58:30	58:30	58:30	44:00	44:00	44:00	58:30	58:30	41:00	41:00
Average travel time 14-16	15:00	15:00	17:00	17:00	13:00	13:00	15:00	13:00	13:00	13:00	17:00	17:00	13:00	13:00
Average travel time 16-19	12:00	12:00	12:00	12:00	08:00	08:00	12:00	08:00	08:00	08:00	12:00	12:00	08:00	08:00
Average travel time 19-22	10:00	10:00	12:30	12:30	08:00	08:00	10:00	08:00	08:00	08:00	12:30	12:30	08:00	08:00
Average travel time 22-25	13:00	13:00	15:30	15:30	11:00	11:00	13:00	11:00	11:00	11:00	15:30	15:30	11:00	11:00
Return travel time	50:00	50:00	57:00	57:00	40:00	40:00	50:00	40:00	40:00	40:00	57:00	57:00	40:00	40:00
Summation of travel times	01:31:00	01:31:00	01:38:00	01:55:30	01:38:30	01:38:30	01:48:30	01:24:00	01:24:00	01:24:00	01:55:30	01:55:30	01:21:00	01:21:00

TABLE III
SUMMARY OF DEPARTURE FROM MINOODAR STOP

Start time Departure	Number of Departures	Proposed Timetable						
7:00	7	7:00	7:18	7:39	7:57			
		7:19	7:28	7:48	6:54			
8:00	11	8:06	8:30	8:54	9:16	9:36	9:56	
		8:18	8:42	9:06	9:26	9:46		
10:00	14	10:06	10:30	10:54	11:21	11:51	12:18	12:42
		10:18	10:42	11:06	11:36	12:06	12:30	12:54
13:00	12	13:06	13:26	13:46	14:06	14:46	15:26	
		13:16	13:36	13:56	14:26	15:06	15:46	
16:00	13	16:06	16:30	16:54	17:26	18:06	18:30	18:54
		16:18	16:42	17:06	17:46	18:18	18:42	
19:00	6	19:06	19:46	20:26				
		19:26	20:06	20:46				

V. VALIDATION

To measure the results and quality of the method proposed in this study, the method must undergo a validity assessment. However, this assessment will require implementing the results on Qazvin bus network schedule and re-surveying the resulting network, which will be very time consuming and will need full cooperation of Qazvin bus service organization; since this approach is currently unavailable, two other methods are used simultaneously for this task. The first method is to use the problem instance solved in the 30th report of TCRP; in this method, we enter the current statistics into the software and then determine the correlation between the results obtained from the proposed method and those of the methodology used in TCRP-30.

In the second method, validity of the introduced method is investigated through an economic analysis. For this purpose, a computer program is developed to investigate the financial-economic condition of Qazvin bus routes. This program, which is developed in Microsoft Excel, is updatable and very easy to use. At this stage, we compare the results of a problem instance solved by MATLAB in the 30th report of the TCRP journal and the ones obtained by coding carried out in this study. As shown in Table IV, the results pertain to two dispatch intervals for an initial and return route with six bus stops.

TABLE IV
A SUMMARY OF THE SCHEDULING RESULTS PERTAINING TO TWO DISPATCH INTERVALS OBTAINED VIA TWO DIFFERENT METHODS

Number of stop	Route	The proposed program (This study)	The proposed program (TCRP-30)
1	First way	07:01	07:00
2		07:05	07:04
3		07:10	07:09
4		07:19	07:15
5		07:25	07:21
6		07:30	07:26
14	Second way	08:16	08:09
15		08:21	08:14
16		08:26	08:20
17		08:34	08:27
18		08:41	08:34
19		08:47	08:40

VI. CONCLUSIONS

In this paper, line number two of Qazvin Municipality Bus Organization is studied as a case study. Two of the most important parts of this study were to determine the number of stops and scheduling fleet. According to Table I, results of solving the model is given, as it can be observed the number of stops decreased from 33 to 20. Time of every going and coming back cycle had 22 minutes decrease, consequently showed that the distance between stops increased from 464 to 583 meters. Obviously, the number of stops decreased while the average distance between stops increased. Unlike sending fleet and scheduling in different studies, the proposed method in this paper is in a way that the line control officer is able to have time offset. Correspondingly, if the line control officer could not send buses in the due time, he or she would send a number of required buses at specific intervals of departure time table in order to keep the overall shape of the timetable. By applying and loading the schedule on the studied line, number of fleet decreased from 17 to 11 buses that this providence in other lines is great help for Qazvin Municipality Bus Organization in operating fleet.

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