Evaluation of Effective Factors on Travel Time in Optimization of Bus Stops Placement Using Genetic Algorithm

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Abstract. In congested cities, locating and proper designing of bus stops according to the unequal distribution of passengers is crucial issue economically and functionally, since this subject plays an important role in the use of bus system by passengers. Location of bus stops is a complicated subject; by reducing distances between stops, walking time decreases, but the total travel time may increase. In this paper, a specified corridor in the city of Rasht in north of Iran is studied. Firstly, a new formula is presented to calculate the travel time, by which the number of stops and consequently, the travel time can be optimized. An intended corridor with specified number of stops and distances between them is addressed, the related formulas to travel time are created, and its travel time is calculated. Then the corridor is modelled using a meta-heuristic method in order that the placement and the optimal distances of bus stops for that are determined. It was found that alighting and boarding time along with bus capacity are the most effective factors affecting travel time. Consequently, it is better to have more concentration on indicated factors for improving the efficiency of bus system.

1. Introduction
The bus system due to handling a large number of passengers is known as an environmental friendly system. With the development of cities and traffic congestions, a big challenge against transportation system in urban areas has been created. Inefficiency of public transportation system, particularly bus system makes passengers use their own cars, which causes traffic congestion and the increase of single-seat cars. Unsuitable location of bus stops and the distance between them are the most important and effective factors in the bus system inefficiency. Generally, there are three parameters that play roles in spacing between bus stops: walking time, riding time and operating time. If stops are close to each other, the speed of passenger movements decreases, and causes an increase in buses’ moving time while passenger access distance and their walking time decrease. However, long distances between stops cause an increase in the time and walking distance and decrease the tendency to use the buses [1]. Thus, reasonable spacing between the bus stops is an important issue. It can decrease traffic congestion, increase efficiency and comfort in transportation that cause an improvement in the time of movements and acts as an important factor in scheduling of public transportation. Although, many studies have been done about optimizing the location of bus stops in recent years, given that in most of them, the modelling has been
done based on some variable factors like ratio of walking time to in-vehicle time, they are not suitable for Iran. Therefore, it is necessary to define a model which is compatible with Iranian traffic characteristics. Hence, the objective of the study is to define a new model by which the number of stops and travel time can be calculated and uses Iranian traffic parameters to find the optimal number of bus stops.

2. Literature Review

Reviewing of available books and papers shows that spacing between bus stops has attracted the attention of many researchers and urban planners. Most efforts among researchers are focused on finding the standard value as an optimal distance between bus stops. The difference in the results obtained in previous studies indicates that various parameters influence the optimal distance of bus stops and by changing each of them, the intended distance is different.

Some of the past researches, which had been done, were focused on the reduction of passengers walking distance. Ceder [2] did the optimization of bus stops locations on the basis that passengers travel shouldn’t start far away from a standard value. Bowerman et al. [3], has created a real model from passenger allocation to the stops and calculated the optimal distance of bus stops according to the decrease in bus stops spacing and the passengers walking distance. El-Shair [4] has tried to calculate the optimal distance between stops using GIS data analysis. He assumed that spacing between bus stops would be satisfying if more than 80% of the properties which are residential or commercial are located in an area within a radius of 300 meters away from the bus stops.

Some other researches done on the distance of bus stops were done with a focus on travel and waiting time. Vuchic and Newell [5] presented a model with the aim to minimize travel time in which route length and the number of stops were variable. Fernandez [6] showed that buses spend a lot of their total travel time at the stops. Thus trying to minimize this time is the best approach for optimizing the distance of stops. He came to this conclusion that stops are the main concerns of the utilization of the bus system. Dell'Olio et al. [7], have proposed a model on the basis of optimizing the bus arrival times and distance between stops simultaneously.

Some other past studies done on the various costs of public transportation systems and weighting were done on the different parameters which had effects on them. Furth and Rahbee [8] have used a combination of data related to bus system and GIS to present a model for finding the optimal distance between stops. They calculated an optimal distance by weighting to accessibility, riding and operating costs. According to the conclusions obtained from their model, the number of stops on the study route decreased from 37 to 19, and the distance between them increased from 200 meters to 400 meters. Lao Yang and Liu Lin [9] concluded that the local population, transportation network and traffic patterns determine the passengers demand, and the geographic conditions of the area have a major effect on the efficiency of public transportation system.

Since 1975, many genetic algorithms have been applied to the different parts of transportation studies, and its borders have been developed over time. The majority of current studies are done on the transportation network, obtaining the optimal design of roads network, and optimizing the distance between stops and their locations. Chakroborty [10] has used a binary genetic algorithm to solve the problem of scheduling the buses at the stops. He aimed at minimizing the transportation time included the total travel time of moved passengers in the centre of displacement and the passenger initial waiting time for boarding to the bus at the stop. The result showed that a model based on genetic algorithm is simply able to find the optimal timing without doing complicated calculations. Chakroborty [11] also created a mathematical calculation program for bus’s scheduling problem in multiway network and analysed them by a series of mathematical complicated calculation. In this paper, a genetic algorithm was used to find the optimal timing of buses in a multiway network with the assumption that the bus
capacity is greater than the passengers demands and their arrival time certainly happens. He et al. used a process for a certain number of routes to determine the effective routes in transportation. Gao-zheng et al. [12], have carried out a function optimization using genetic algorithm, which targeted the total costs such as: access, time, walking, usage costs and so on by applying coefficients of a function. Christos [13] minimized the targeted function using genetic algorithm in which the parameters, including walking time, riding time and operating time turned into economical parameters based on a dollar per unit time. Bin Yu et al. [14], provided a bi-level programming model to determine the required number of buses. Their aim was to determine the optimal number of buses needed to reduce the total travel time which is affected by the capacity of each company’s fleet and the route choice behaviours of the passenger. In order to solve this bi-level model, they used an iterative approach, which included a genetic algorithm and a label-marking method. The results showed that this optimization method can improve a company’s local level of service. Furthermore, the efficiency of resources and the transit systems’ overall level of service can be improved by incorporating different companies properly.

3. Methodology and Formulas Required

In this paper, a new formula is provided to calculate the travel time, by which the number of stops and consequently, the travel time can be optimized. Firstly, a corridor designed with specified number of stops and distances between stops is addressed, the related formulas to travel time are created, and its travel time is calculated. Then the corridor is modelled using a meta-heuristic method in order that the placement and the optimal distances of bus stops are determined.

The objective function equation is as follows:

\[ T = T_i + T_o \]  \hspace{1cm} \text{(1)}
\[ T_o = T_1 + T_2 + T_3 \]  \hspace{1cm} \text{(2)}
\[ T_i = T_4 + T_5 + T_6 + T_R \]  \hspace{1cm} \text{(3)}
\[ T_1 = \frac{p \times d_1}{v_p} \]  \hspace{1cm} \text{(4)}
\[ T_2 = \frac{A \times d_2}{v_p} \]  \hspace{1cm} \text{(5)}
\[ T_3 = p \times \frac{n - 60}{2} \]  \hspace{1cm} \text{(6)}
\[ T_4 = \frac{p \times d}{v} \]  \hspace{1cm} \text{(7)}
\[ T_5 = s \sum_{n=1}^{Q} T_{n} \]  \hspace{1cm} \text{(8)}
\[ T_6 = s \sum_{n=1}^{Q} T'_{n} \]  \hspace{1cm} \text{(9)}
\[ T_{in} = \left[ (\sum_{z=1}^{n} P_z - \sum_{z=1}^{n} A_z) / S \right] \times 1/ \left[ K_a \left( P_{o} T_{o} / S \right) + \left( P_{b} T_{b} / S \right) \right] + 1/ \left[ K_a \sum_{n=1}^{Q} (T_{n}) / S \right] \]  \hspace{1cm} \text{(10)}
\[ T'_{n} = \left[ \frac{\sum_{z=1}^{n-1} P_z - \sum_{z=1}^{n-1} A_z}{S} \times T_{d1}/2 \right] + \left[ \frac{\sum_{z=1}^{n} P_z - \sum_{z=1}^{n} A_z}{S} \times T_{d2}/2 \right] \]  \hspace{1cm} \text{(11)}

\( T_o \): Passengers elapsed time out of the bus
\( T_i \): Passengers elapsed time in the bus
\( T_1 \): Passengers walking time from origin to stop
\( T_2 \): Passengers walking time from stop to destination
\( T_3 \): Passengers waiting time in stop
\( T_4 \): Passengers in-vehicle travel time along the route
$T_s$: Passengers wasted time because of alighting and boarding time

$T_a$: Passengers wasted time because of acceleration and deacceleration.

$T_R$: Red-light time along the route

\[
T = P \left( \frac{d_p + d_A}{v_p} + \frac{d}{v} + \frac{h - 60}{2} \right) + S \sum_{n=1}^{Q} T_{t_n} + S \sum_{n=1}^{Q} T'_{t_n} + T_R
\]  

(12)

$P$: Total demand in the peak hour. It is obtained from the origin-destination matrix arrays of the travel.

$d_p$: The passenger average walking distance from origin to stop. Its amount is obtained by dividing passenger total walking distance from each cell up to the cell including the corresponding stop by the total number of trips in the peak hour.

$d_A$: The passenger average walking distance from the cell consisting of the destination stop to the destination cell. Its amount is obtained by dividing passenger total walking distance from the stop to the destination by the total number of trips in the peak hour.

$v_p$: The passenger average walking speed on bus route.

$d$: The average distance travelled by passengers by the bus. Its amount is obtained by dividing total amount of distance of the cell consisting of the origin stop to the cell consisting of destination stop by the total number of trips in the peak hour.

$V$: The average speed of bus. ($m/s$)

$h$: Headway of bus in peak hour. (s) (Assuming uniform distribution of passenger’s arrival time at stops, h=600 s)

$S$: The number of buses that could pick up all the passengers at peak hour. (S=6)

$T_{t_n}$: The wasted time caused by alighting and boarding of passengers at the stop n. (s)

$T'_{t_n}$ : The wasted time due to the increase and decrease of the bus speed at the stop n.(s)

$\sum_{z=1}^{n} P_z$: The sum of passengers boarded the bus to the stop n.

$\sum_{z=1}^{n} A_z$: The sum of passengers alighted from the bus to the stop n.

$P_b$: The number of passengers that boarded the bus at the stop n.

$P_a$: The number of passengers that alighted from the bus at the stop n.

$T_b$: The time required for each passenger to board the bus. (s)

$T_a$: The time required for each passenger to alight from the bus. (s)

$K_s$: Number of passengers boarding the bus simultaneously.

$K_a$: Number of passengers alighting from the bus simultaneously.

Q: Number of stops
$T_d$: Dead time per stop (s) (Assuming $T_{d1} = T_{d2} = T_d/2$)

4. Assumptions and Corridor Characteristics

The studied corridor in this paper is a route which is 8 kilometres in length divided into 80 cells. The mentioned corridor is located in the city of Rasht in the north of Iran, and the surrounding lands are commercial, administrative and residential. According to Rasht transportation and traffic organization [15], the level of service of this route has decreased gradually, and its efficiency has reduced dramatically in recent years. For this reason, it is recommended that exclusive lanes should be made in the median for buses and there would be two lanes beside the median on each side of the route for other traffic flows. There are not any delays caused by stopping in traffic jam, but because of three signalized intersections, red-light time should be added to total travel time due to stopping behind the signals at the intersections. Moreover, it should be said that, because of smooth traffic flow around the mentioned unsignalized roundabout, there isn’t any considerable delay that affects the bus system. By considering LOS A for this route, the number of buses serving at peak hour must be equal to six.[16] Moreover, dead time per stop is equal to 5.5 s.[17]

Travel time calculation and optimizing bus stops spacing along the route will be done for peak hour. The time it takes passengers to walk from the origin of the bus routes, due to being constant and fixed in case of selecting any other vehicles, will not be included in calculation and only the pedestrian walking time along the route will be important. All travel demands generated from both sides of the route are considered as total demands on one side of the route. The criterion for selecting a bus stop by passengers is to achieve it in the shortest possible time. When the passengers enter a point between the two stops, the previous stop would be chosen. It is also assumed that passengers will not use bus for the distances of less than three cells. Thus, the number of trips made from each cell to the next two cells will be zero.

5. Modelling and Optimization Using Genetic Algorithm

5.1. Modelling Process

How to generate and attract trips to all the cells is determined by an $n \times n$ matrix. The columns of this matrix represent the trip generating cells, and the rows of the matrix represent the trip absorbing cells. The arrays of the matrix will be the number of trips made from the origin cells to the destination cells at peak hour.

5.2. Design Variables

To analyse this route, its length is divided into 100 meters long cells, and there are 80 cells along the route. The cells known as 18, 26, 42, 52 and 80 are placed in intersections. It is assumed that in this route except the first and last cell, the remaining stops are located 500 meters apart (five cells) from each other. So the cells known as 1, 6, 11, 16, 21, 26, 31, 36, 41, 46, 51, 56, 61, 66, 71, 76 and 80 have their own stops.

5.3. Objective Function and Optimization Process

The objective function in this paper is to minimize the total travel time (Eq.12). Considering passengers allocation to stops, provided that they reach in the shortest time, the total travel time could be calculated. After receipt of production-absorbing matrix by the model as an input, it starts to produce the initial population, which is here to insert different number of stops along the route, then using the above relations to determine travel time for the route, and the best placement between inserting repetitions for the desired route; it separately introduces as “optimal placement” for any number of stops. The conceptual flowchart of the optimization process is given in figure 1.
6. Analysis of the Results

Default values used in relations are obtained from local traffic information considering the reference values [18]. After the modelling, it was proved that the model tends to insert the most possible stops in the corridor due to the saturation mode at the peak hour. Thus, most of travel time will happen in a situation that the minimum number of stops are used in the corridor. Since the lands surrounding the route are commercial, administrative and residential, and the minimum distance between stops in urban areas is 150 meters [16], given that each cell is 100 meters in length, locating large number of stops on the desired route will be possible.

As it is seen in figure 2, the least travel time obtained from modelling is about 16.5 minutes that in case of its existence, there are 72 stops that can be seen. Also, by reducing the number of stops along the route, travel time increases and if there are 6 stops, it will be 30 minutes which is the highest travel time. In comparison with the utilization of 72 stops which it leads to the least travel time (16.5 minutes), the use of 15 stops, with the reduction of 57 stops, which drastically reduces the cost of construction and maintenance, has only about 4 minutes more travel time. So, it can be used as an accepted sample to determine the placement and spacing of stops in this route. Beside the result obtained from the model, which can be seen in figure 2, the best placement of bus stops is shown in figure 3. According to optimization process results and surrounding lands characteristics, if 15 stops are in use, choosing the
cells 1, 7, 14, 18, 26, 29, 34, 42, 46, 52, 57, 64, 68, 76 and 80 will be the best condition for the placement of stops along this route.

![Diagram showing travel time and bus stops](image1.png)

**Figure 2. Results of Default Values**

![Map showing bus route](image2.png)

**Figure 3. Location of bus stops along the route.**
6.1. The Impact of Passenger Boarding Time on Travel Time

Numerical results on a designed corridor shows that there is a considerable travel time spent by buses at the stops. This parameter is directly affected by passengers boarding and alighting time from the bus. As it is seen in figure 4, with increasing time of each passenger boarding the bus, the total travel time increases which this increase is due to increased stopping time at the stop. When 15 stops are selected along the route, by increasing the passenger boarding time from 2 seconds to 4 seconds, total travel time will change about three minutes, if this time increases to 8 seconds, travel time has more change than previous condition, and it increases to 29.57 minutes. By increasing the bus stops and higher boarding time, more travel time is tangible.

Figure 4. The Impact of Passenger Boarding Time.

Figure 5. The impact of passenger alighting time from buses considering $K_a = 2$. 
6.2. The Impact of Passenger Alighting Time from Buses on Travel Time

Considering one wide exit door for the bus by which two people could alight from the bus simultaneously or two regular exit doors, the following condition is resulted. When there are 15 stops along the route, travel time is 20.34 minutes under normal condition. If this time increases to 2.5 seconds, the travel time will be 21.92 minutes, and when it increases to 4 seconds, the travel time will be 24.17 minutes.

This increase in travel time is much more remarkable for the buses with one regular exit door. As it is seen in figure 6, by increasing the passenger alighting time from 2 seconds to 4 seconds, total travel time will change about three minutes, if this time increases to 4 seconds, travel time has more change than previous condition, and it increases to 27.5 minutes.

Figures 5 and 6 show that, increase in alighting time have noticeable effect on travel time like increase in boarding time. It confirms the importance of stopping time at stops. So trying to improve this parameter will have great impact on bus system performance and the reduction of travel time. Furthermore, the improvement of this parameter can be economically beneficial.

![Figure 6. The impact of passenger alighting time from buses considering $K_a = 1$.](image)

6.3. The Impact of Changes in Average Speed of Buses on Travel Time

Average bus speed is a factor that is strongly influenced by other traffic flows. As it is mentioned earlier, it is assumed that the intended corridor has a bus exclusive lane and faces delays at three signalized intersections due to red-light time. Figure 7 shows that by increasing the bus speed from 30 to 50 kilometres per hour, small changes in travel time and slope can be seen. This clearly shows that the most effective factor in determining travel time is the time spent statically at the stop, which is directly affected by the demand, passenger boarding and alighting time from the bus.
6.4. The Impact of Changes in Pedestrian Walking Speed on Travel Time

As seen in figure 8, by reducing and increasing the average speed of pedestrians, travel time will change insignificantly. Considering 15 stops along the route, the travel time will be 19.22, 20.34 and 21.29 minutes for these three pedestrian speeds modes. The range of travel time, by increasing the average speed of pedestrians, will be between 16.4-31 minutes, and have a slight difference with the normal condition. By looking at the figure 8, it can be concluded that changes in the pedestrian walking speed in a large number of stops, it will be less effective, but in small number of stops, it has more effect than previous condition. This reflects the fact that by reducing the number of stops and increasing walking distance, passengers walking time will be more important.

6.5. The Effect of Bus Capacity on Travel Time

With the increase in bus capacity, the number of buses required to service at peak hour reduced. As seen in figure 9, by reducing the capacity of buses from 120 to 90 people, which provides more buses to service at the peak hour, the travel time will be reduced to 18.79 minutes. While by increasing the capacity to 180 people and proportionally reducing their number to service at the peak hour, this time changes to 26.23 minutes. It can be concluded that by using ordinary buses and buses with fewer capacity instead of articulated buses and reducing the headway, travel time will be reduced.
6.6. The Impact of Changing Dead Time per Stop on Travel Time

As seen in figure 10, there is not any remarkable difference between travel times for three different values of dead times per stop. Considering default condition with 15 stops, the travel time will be 20.18, 20.34 and 20.94 minutes for different dead times per stop values. Therefore, it can be concluded that this factor has the least effect on travel time and it is better to focus on more effective factors, which are mentioned earlier.
7. Conclusions

The proper location and design of bus stops are the most important factors that affect the effectiveness and efficiency of public transport bus service. In this paper, genetic algorithm has been used for analysing the data and generating the optimization model. Firstly, considering the placement of stops during the route, total travel time was calculated, and then an optimization process was used to determine the best placement of bus stops in order to minimize the total travel time. Studying the information and figures obtained from the output model indicate that at the demand peak hour, the model prefers that the distances between stops are reduced. It can also be concluded that the greatest influence on determining the travel time of passengers in the bus system in city of Rasht belongs to alighting and boarding time along with bus capacity. Therefore, attempts to improve these factors and using buses with reasonable capacity can have an effect on the travel time more than any other parameters and consequently cause more people to use the bus system for moving within a city. However, the results are quite general and should be applicable for cities with these similar traffic characteristics.

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