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Analyzing of Bus Operation to Obtain Regular Frequency for Neo-mission

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Abstract: Nowadays, number of urban journey is increasing due to rapid economic growth in developing country. Since government policy is to encouragement people to using the public transportation. In the meantime, Buses network is biggest public transportation in urban area, because it is operating costs and administrative costs are cheaper than other public transportation means. One of important problems in bus operation is decline the delays of buses. Unfortunately, during a traffic jam and high volume of passenger demand the delays of buses is very plenty. This article represents an analysis of new method for bus operation, which reduces the delays of buses to running their operation. Methodology of this study is using the exclusive bus lane in one part of bus route. Hence, a case study based on an actual public bus operation in Tehran, Iran is used to demonstrate the usefulness of devoting a specific lane for bus service. It was found operators of transportation service want to reduce the delays of buses due to not increase their fleet size. It has been highlighted where buses using exclusive lane, their delay is reduce and arrive in destination terminal timely. The results of case study also can a useful method for long bus lines in large cities of the developingcountries.

Key words: Efficient bus lane, Passengers behaviour, Waiting time, Delays of bus operation.

INTRODUCTION

Buses are the most widely used in transit technology today because bus networks are easily accessible and cheaper than other kinds of public transportation. They are operated in nearly all cities with transit service and in a majority of them are the only transit modes.

Studies of improving the performance of bus services are important because of the increasing demand patterns of passengers. On the other hand, operating cost of bus services is lower than other types of public transportation. Verifying the case of cost is important in optimization public transportation. Generally, cost is divided into two parts: direct costs and indirect costs (Ibeas *et al.,* 1996). Furthermore, the cost of bus service includes operating cost and the cost of users which if they are minimized can increase efficiency (Wirasinghe and Vandebona, 2010), an objective for all societies to achieve (Meignan *et al.,* 2007). Overall, the evaluation of bus service can conducted from three points of views: travellers, operators and authorities (Chen *et al.,* 2009). One of the specifications to improving performance is the devotion of a specific lane for their services. And, this can be implemented in three major ways: mixed traffic lanes (MTL), regular bus lane (RBL), and exclusive bus lane (EBL) (Vuchic 1981). In MTL, bus routes are dedicated to urban mixed traffic. In other words, buses move alongside other motor vehicles and non-motorized vehicles in a street. In RBL, there is a specific lane for bus services during peak period traffic where the route is separate from other vehicles. Besides this, a contra-flow

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bus lane can allow buses to travel in the opposite direction to other vehicles (RBLs). Finally, in EBL there is an exclusive bus lane for the use of the buses separated from other traffic at all times of a day.

Bus operation during day has more interactions whit other traffic, such as: traffic lights, intersection and spacing of their bus stops.Traffic lights can to affect to disorganization of buses schedule. Where, times of red light and arriving time of buses on traffic light do not coordination. Main and subsidiary intersection along bus route is to increase more stop bus and finally due to decrease average of bus speed (Hafezi and Ismail, 2011).Spacing of bus stops has directly effective in instantaneous speeds and acceleration rates of buses and walking space of passengers. More intervals between bus stops caused increasing speed and accordingly increasing reliability of service. On the other hand, increasing space between bus stops is increased walking space for passenger and less area coverage. Generally, spacing bus stops is related to the ratio of passenger on area.

Locations of bus stop are divided into three parts: near-side, where bus stops is at an intersection before crossing the cross street. Other type is far-side, where bus stops is at an intersection passed the cross street. And, last type is midblock, where bus stops is away from intersections. Design of location bus stop is better out of the route (Hafezi and Ismail, 2011). This design caused increasing safety and decrease interference with other traffic. Also, when the bus stops at the station, it not blocks one of the lanes and other vehicles can use the other lane to carry on with their journey.

Generally, schedule of bus service can divided two time of operation: peak-hours of traffic and non-peak hours of traffic. Indeed, the first time is including working day and second time is including weekend and holidays. Uttermost disorganization of bus schedule is duration peak-hours traffic. Where, due to traffic congestion and high number of passengers cause more delays of buses and they arriving in destination after planning time (Carlos and Luis, 2009). And bus authorities are forced to increase fleet size for compensation of scheduling. Which, this practice cause increasing operating cost (Yan and Chen, 2002).

In recent years, some studies have been conducted to decrease disorganization of bus schedule. Nagatani (2001) presented a solution passing the bus stop when number of passenger in bus is full or headway profile is further limit. Sun *et al.,* (2008) presented division of paths among bus stops for decline the disorganization of bus schedule. Also, Fang *et al.,* (2010) presented variable route bus. Gleason (1974) presented the decision maker method for dispatching buses in different frequency. Observance of real-time departure of all buses existing in origin station according schedule can reduce delays in their missions (van Oudheusden and Zhu, 1995; Lam *et al.,* 2009). Merging bus routes was another solution that presented (Hwe *et al.,* 2006).

In this paper, we analysis bus operation for obtain the effective parameters to increasing fleet size. Which, this analysis is including trade off between some parameters such as: spacing of bus stops, average speed, dwell time and recovery time. Finally, result of analysis is checked in actual public bus operation in Tehran, Iran.

Prototype Bus Service Model:

After describing the different of bus paths, in this section, we first discuss the problem of disorganization bus schedule. Then we define of symbols. Finally, the prototype bus service model is discussed.

Problem of Disorganization Bus Schedule:

Considering to bus operations are done on duration different hours in day and week (weekdays and weekend), average of round-trip time and passengers demand for using the bus have fluctuation. Namely, duration peak-periods traffic travel time is longer than duration off peak-periods traffic. Also, passenger demand for using the bus network duration peak-periods traffic is more than duration off peak-periods traffic. This study focuses to regulate frequency of bus operation for adjustment fleet size. Since, can with survey in different conditions of bus operations, can to obtained fluctuation rate.

Note that is possible duration done bus operations in day some buses note be able to operate for various reasons, such as: preventive maintenance, bus driver absenteeism and etc. since, this possibility should be considered in calculation in total number of fleet size.

Parameters Definition:

In this paper, notations are defined as follows:

n is the number of bus stop on inbound way, $n = 1,2,3,...,j$.

n' is the number of bus stop on outbound way, $n' = 1,2,3,\ldots, j'$.

d_n is the distance between two consecutive bus stops on inbound way

$d_{n'}$ is the distance between two consecutive bus stops on outbound way

$\bar{V}_n$ is the average velocity of bus between two successive bus stops

$\bar{V}I$ is the average velocity of bus on inbound way;

$$\bar{V}I = \sum_{n=1}^{j} \bar{V}_n \Big/ j$$

$\bar{V}U$ is the average velocity of bus on outbound way;

$$\bar{V}U = \sum_{n'=1}^{j'} \bar{V}_{n'} \Big/ j'$$

tSI is the spend time in origin terminal

tSU is the spend time in destination terminal

RC_L is the recovery time in origin or destination terminal

$L \in \{O,D\}$

E is the elapsed time for entering and exiting of bus from bus stop

B_n is the number of boarding passenger in bus stop n

A_n is the number of alighting passenger in bus stop n

P_p is the total number of passengers per hour

C_p is the overall capacity of bus

α is the coefficient time for boarding one passenger on bus at bus stop

β is the coefficient time for alighting one passenger on bus at bus stop

γ is the coefficient of bus capacity

c is the number of channels of bus

Prototype Bus Service Model:

Required parameters for prepare bus schedule model is including: round-trip time, frequency and fleet size (Grava, 2002).

Round-trip time for the bus mission between origin and destination station in one closed loop when the bus starts from origin terminal and services in each bus stops along the bus route, and arrive to destination station. After recovery time in destination terminal, begins a back services with coverage of all station in back way.

Finally, after arriving in origin terminal and recovery time in there, the bus begins the next round pursuant frequency from the schedule (Figure 1).

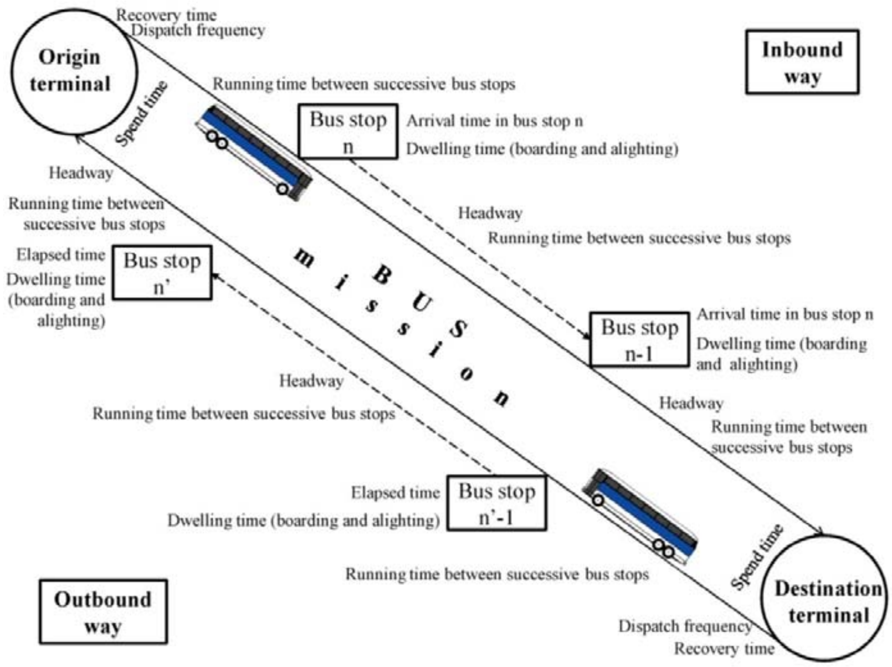

Fig. 1: Round trip-time for bus mission.

The equation of round-trip time is consists of the journey time on inbound path and journey time on outbound path andit is given by

$$T_{rt} = TI + TU \quad (1)$$

The first component from Equation (1) is journey time on inbound path is given by

$$TI = \frac{\sum_{n=1}^{j} |d_{n+1} - d_n|}{\bar{V}I} + tSI + \sum_{n=1}^{j} D_n + RC_L \quad (2)$$

The first component onEquation (2) is total running time between bus stops along the bus route excluded dwell time in bus stops and other stops, and this is achieved by physical formula which obtained from dividing the total distance between bus stops along the bus route to the average velocity.

The second component on Equation (2) is spend time, tSI, and it is a constant value is. It value can beexperimentally determined. Indeed, it is in terminal, when the bus goes out the parking space and arrival at the first bus stop for boarding passengers and when the bus after dropping passengers in last bus stop goes into parking space. In some terminals where there is embedded a situation for boarding passenger in the inside terminal, spend time is lesser than where terminals do not have this situation. For obtain it value can used the average value of site observation.

The third component on Equation (2) is total of dwell time in each bus stop along the bus route. Dwell time is the time bus stops in each bus stop. It time includes time for boarding and alighting passengers in bus stops. Dwell time is equivalent to the maximum value of boarding passenger time and alighting passenger time plus the elapsed time for entering and exiting of bus from bus stop. Elapsed time is a constant value is Equation (2). It value can beexperimentally determined. For obtain it can used the average value of site observation and given by (Hafezi and Ismail 2011).

$$D_n = \max[TB_n, TA_n] + n.E \quad (3)$$

The boarding passenger time isequivalent to the coefficient time for boarding one passenger on bus multiplied by total number of boarding passenger divided to number of channels on bus and given by

$$TB_n = (\alpha . \sum_{n=1}^{j} B_n) \Big/ c \tag{4}$$

The alighting passenger time is equivalent to the coefficient time for alighting one passenger on bus multiplied by total number of alighting passenger divided to number of channels on bus and given by

$$TA_n = (\beta . \sum_{n=1}^{j} A_n) \Big/ c \tag{5}$$

Constant coefficient α and β can beexperimentally determined.Number of boarding and alighting passengers for each bus stop along the bus route is obtained through statistics methods.

The forth component onEquation (2) is recovery time. It is the extra time for rest crew and schedule adjustments in bus terminal.

The second component from Equation (1) is journey time on outbound path is given by

$$TU = \frac{\sum_{n'=1}^{j'} \left| d_{n'+1} - d_{n'} \right|}{\bar{V}U} + tSI + \sum_{n'=1}^{j'} D_{n'} + RC_L \tag{6}$$

All parameter and definition are same as inbound way, except that they are calculate with outbound way value.

Fleet size for operation in one hour is equivalent to divide the total number of passengers in one hour by capacity of bus. Total number of passenger is obtained through statistics methods. And other parameter is capacity of bus, which it is overall bus capacity including seats and standing space. In reality, duration peak-hours of traffic passengers used more than standard capacity of buses, therefore is multiplied γ coefficient to standard capacity of bus

The fleet size for operation in one hour is given by

$$N_B = \frac{P_p}{\gamma . C_p} \tag{7}$$

The value of γ can beexperimentally determined.

Frequency buses are interval time between send two successive buses for do to mission along their route and are given by

$$f = \frac{60}{N_B} \tag{8}$$

Total number of fleet size is number of buses needed to perform correctly the service for specified path and is given by

$$N_B = \frac{T_{rt}}{f} \tag{9}$$

To devoted fleet size for both ways in the beginning mission is equivalentwith difference by arrival time of first bus in initial station in origin terminal with arrival time of same bus in ending station in destination terminal plus journey time on inbound path divided to frequency of buses and it is given by

$$N_B^O = \left(\left| AT_{1,1}^O - AT_{1,1'}^D \right| + TI \right) \Big/ f \tag{10}$$

Also, is determined number of bus for outbound path from difference whit total number of fleet size and it is given by

$$N_B^D = N_B - N_B^O \tag{11}$$

In the following this sections, we discuss about variable parameter round-trip time equation which, by increasing and decreasing it the value of round-trip time is varied and finally cause disorganization in bus schedule.

Effective Parameters in Disorganization Computing of Round-Trip Time:

Generally, prepare the prototype bus service model is determined by three major parameters including: round-trip time, frequency and fleet size.

From Equation (2)-(5), one obtains the equation of round-trip time in terms of effective time and it given by

$$\begin{aligned} TI = \frac{|d_2 - d_1|}{\bar{V}_1} + \frac{\sum_{n=2}^{j} |d_{n+1} - d_n|}{\bar{V}I} + tSI + \max[(\alpha.B_1)/c\,, (\beta.A_1/c] \\ + \max\left[(\alpha.\sum_{n=2}^{j} B_n)\Big/c\,, (\beta.\sum_{n=2}^{j} A_n)\Big/c\right] + n.E + RC_L \end{aligned} \tag{12}$$

Time dependent parameters are including average speed of bus, boarding and alighting passengers and recovery time.

Regular spacing bus stops can prevent from reducesaverage speed of bus. Equal spacing bus stop can help to bus driver to adjust the instantaneous speeds and acceleration rates (Bermond and Ergincan 1996). For reducing boarding time can use the magnetic card such as touch-n-go (Pelletier *et al.,* 2011). Using the magnetic cards instead of cash for fare payment can reduce boarding time. It takes about 8 seconds for each passenger in dwell time, the time consumed will be about 4 seconds on average as it takes 10 to 15 seconds for using the magnetic cards and cash, respectively. To decrease alighting time can separate doors in buses for leaving off. Finally, can using from recovery time to adjustment the frequency and compensate delays of bus duration peak-hours traffic (Hafezi and Ismail, 2011).

The constant parameters including spend time and elapsed time can reduce whit change in physical structure of bus station and improving access way.

In the following sections, we are investigating an actual public bus operation in Tehran, Iran by compare round-trip time in two versions: (A) statistic structure, (B) actual structure.

Statistical Analysis:

An actual public bus line operation in Tehran, Iran was selected to analysis this study. Total Length of this bus line is about 10,950 m from west to east where the transfer of passengers from suburban areas to the city centre takes place. The total number of passenger transfers with this line is 18,700 per day.

It has 15 bus stops and two terminals where the origin and destination line terminals were used only for parking buses and crews rest and not for boarding and alighting passengers. To organize passengers, a metal framework in each bus stop is used. Some bus stops are shared stops with other lines. These stations are larger compared to the non-shared ones. While, the first bus stop is for boarding passengers from the origin line, the last bus stop is for alighting passengers from buses in the destination line.

The total number of buses is 22 and all of them are of one make. Each bus has 45 seats and the total capacity is 75 people. The routes of this bus line are composed of two sections: the first has mixed traffic lanes with a distance of 6,240 m served by 8 bus stops and the second is the exclusive bus lane with a distance of 4,710 m and 7 bus stops. Generally, the traffic route is divided into three periods: first, peak-hour traffic in the morning, second, traffic hours during the day, and third, peak-hour traffic in the afternoon.

From the route information of the bus line to be studied in this paper, the distance and layout table between bus stops given in Table 1 can be derived.

Table 1: Distance and layout of bus stops.

Stop number	Distance (m)	Layout
1	0	MTL
2	950	MTL
3	650	MTL
4*	450	MTL
5	360	MTL
6*	900	MTL
7	600	MTL
8	380	MTL
9*	1400	EBL
10	550	EBL
11	400	EBL
12	550	EBL
13*	1100	EBL
14	330	EBL
15	380	EBL
16	1100	MTL
17	850	MTL

* Bus stop is shared stop with other lines.

For selecting the number of buses needed for a bus line, some conditions have to met, for instance, the geographical and length of route, bus type and passenger demand. One way of lowering the waiting time for the bus arrival on long routes is to increase the number of buses. Another way is use buses with more capacity, such as, articulated bus or Double-decker bus. During peak-hour traffic periods, passenger demand for using the buses is more than during non peak-hour traffic. Figure 2 plots the simulated distribution of one bus load of passenger for a day.

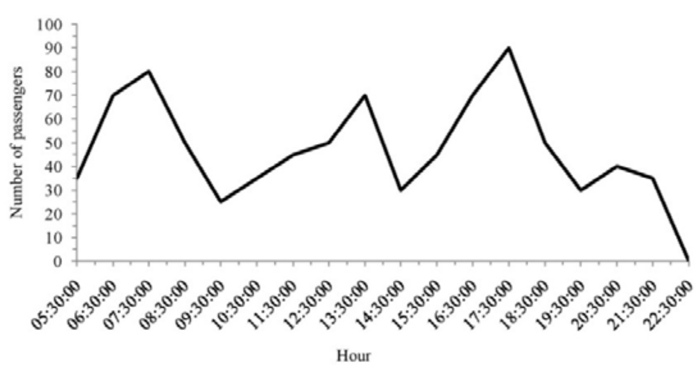

Fig. 2: Modelling measurement of the load of passenger for Tehran bus-network.

Figure 3 represents the actual measure of journey time for bus mission from origin to destination station. Variance between actual and virtual for this measure is around 0.56 percent. To wit, the actual journey time around 0.56 percent is more than the virtual journey time. Average running time (including travel time and stop time) is around 5.15 and 2.87 minute for MTL and EBL ways, respectively. Different reasons have caused an increase in this value. They are traffic jams, traffic lights and large volumes of passenger.

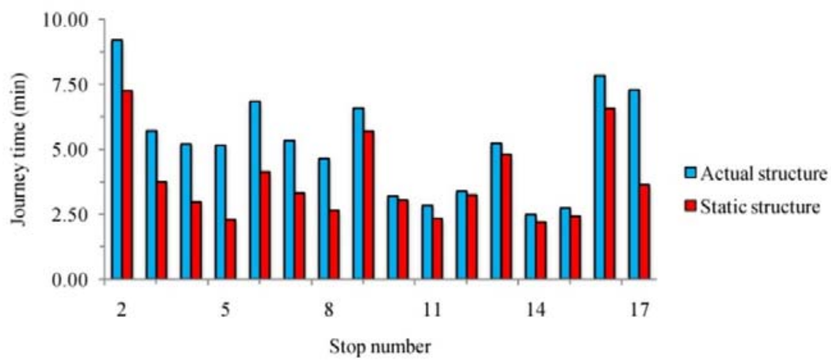

Fig. 3: Modelling measurement of the journey time for Tehran bus-network.s

The average speed of bus in different parts of the route during peak-hour traffic is shown in Figure 4. At period-hour traffic, the average speed of bus is reduced significantly. According to the statistics, the average speed of bus at peak-hour traffic is reduced to around 62% as compared to non peak-hour traffic. The average speed of the bus is around 8 and 13 kilometres per hour for MTL and EBL ways, respectively. Considering the relationship between speed and velocity, if bus stop spacing is of equal amounts, the bus operator can run with symmetric average speed in different parts of the route. Usually, the direct routes in designing bus routes are used not because of diminished acceleration of buses.

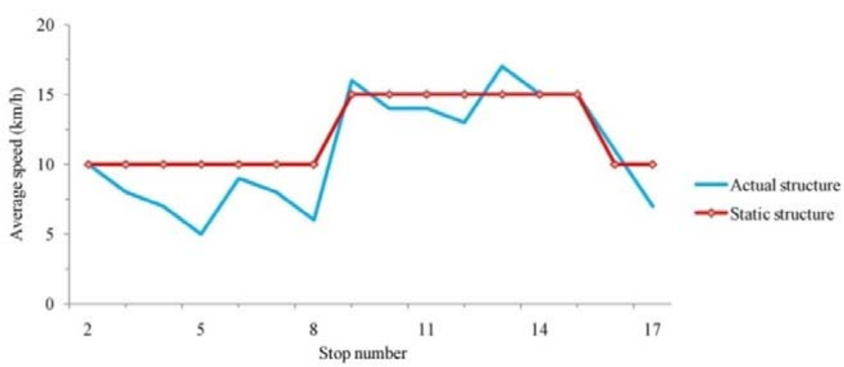

Fig. 4: Modellingmeasurement of the average speed of bus in the peak-hour traffic.

Overall, the behaviour function of delays is linear. The waiting time for bus arrival at the last bus stop is sum total delays occurring in the past bus stops. Delays of bus mission include cases such as delay at departure from first station, traffic congestion and passenger volume. The bus departure from the first station has to be according to schedule. Rest crews should be planned, so they finished before starting on the new mission.

The average speed of bus is reduced at peak-hour traffic causing more delays. Increasing passenger demand at bus stops can cause an increase in time block at bus stops for the bus mission. Delays between two bus missions are as shown in Figure 5. When departure period from the first station is 15 minutes, the average of delays in EBL way is less than that in MTL way.

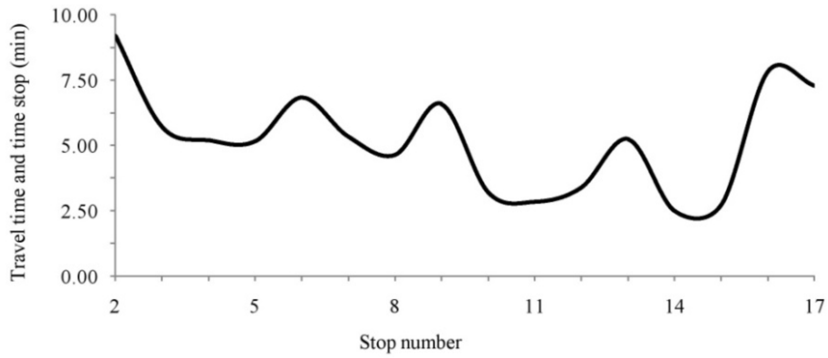

Fig. 5: Delays between two bus missions.

RESULTS AND DISCUSSION

Maximum duration of disorganization bus schedule is duration peak-hours traffic. Where, buses are in traffic congestion and cannot follow the correctly their schedule. According to duration round-trip time, usually all buses have a overlap time whit traffic hours. Bus delay in each bus stop is equivalent by total bus delays in pervious station. Hence, for beginning neo-mission, time of operation is equivalent planning time plus delay time. Buses company for avoiding the high delay of bus for passengers servicing, are forced to add extra buses from other bus lines to that bus line.

The solution for decrease bus delay and done neo-mission in real time according to planning time is using the exclusive bus lane in some part of bus route. Which, buses can to compensate their previous delays in this part. Whit increasing averagespeed subsequently is decreasejourney time and buses can followexactly the planning. By consider a large period for bus operation can to compensate delays along their operation.According to Figure 3 and Figure 4 variance of bus operation in exclusive bus lane is very less than variance of bus operation in mixed traffic lane and it can help to implementation correctly planning.

Conclusions:

In this paper, survey behaviour of passengers and operations of a bus line network in mixed traffic lanes and exclusive bus lane has been presented. Statistical analysis combines volumes of passengers, bus journey time, average speed and delays of bus mission during peak-hour traffic in the morning. We have shown that the use of the exclusive bus lane layout can estimate more bus service reliability with a decline in total delays. Moreover, to improve bus service in crowed areas the mixed traffic lanes and exclusive bus lane can be used together. With increasing average speed of bus in EBL ways and decline running time between bus stops, can compensate delays at the last stations. This approach reduces total delays in bus mission. This approach has been applied and validated on a real case study in a bus-network in the city of Tehran. Probably, it is also a useful tool for many other bus companies in large cities of the developing world.

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