A Dynamic Supply-Demand Model of Fleet Assignment with Reducing Waiting Time of the Passengers Approach (LRT and Bus System of Tabriz City)

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Abstract—**The goal of this research is offering an optimum model for the multi-modal public transportation fleet including LRT and the bus system of Tabriz city with the approach of reducing waiting time for the LRT passengers and scheduling the headway of the fleet. Attending the specifications of the public transportation system and the trip quality of the users of that part of urban transportation system from origin to destination, the trip times more significant than any other factors in the desirability of public transportation system and the amount of its use. As, by reducing the trip time of the passengers, public transportation system is selected as the cheapest and the most safe part of urban transportation system by the users. In this study a dynamic model is presented to determine the optimum assignment of the public transportation fleet in which the optimum policy and combination of the fleet is introduced by marking the joint stations between the lines of LRT and bus lines and also specifying the chosen bus lines for changing the fleet of them and then traffic analysis of urban transportation network according to each of the conversion policies of the fleet. The results get from the optimum model indicates that as for the interference of bus line and personal network, the increase of the bus lines fleet causes more crowding in some paths of the network (from origin to destination) and as such swing of the spent time and traversed distance in the network. This increases the costs for the users of the network. Therefore a assignment of the fleet is desired that makes the least cost for the users of the network.**

Index Terms—**Multi-modal public transportation, waiting time, optimum combination of the fleet.**

I. Introduction

Considering a light rail transit system (LRT) and a regular bus transportation system, each one of these systems have their stations and terminals. The transfer stations for these two models of transportation are in fact defined the common stations between the lines of these two systems.

With optimizing the waiting time in transfer stations moreover that the trip time reduces, the desirability of public transportation system increases too. This could increase the portion of public transportation in urban trips. Optimizing the waiting time in transfer stations that is the main goal of this research is possible through optimizing headway of public transportation vehicles in the lines of the path. Attending the relations between fleet, headway, waiting time, the whole trip time and the effect of whole trip time in increasing the desirability of public transit system, in this study making changes in the fleet and analysis of the system outputs are defined as the main job.

In order to make changes in public transportation fleet, regarding that two main modes of rail and bus transit are taken into consideration by the researcher, there must be changes in the number of fleet of these two systems.

But attending the functional system of LRT in which headway and the number of wagons have an ideal condition and most of the time it is not possible to increase the wagons and decrease the headway because of the technical limitations, the suggested solution is that by preserving the movement specifications of LRT, some changes should be made in bus lines and their headway that result of these changes could optimize the waiting time of passengers in the LRT stations. [1]

To solve this problem, the common stations between two systems and the lines conduced to these stations must be determined to do conversion policies of fleet on the lines and each time the public transportation network should be analyzed. Changes of fleet in each step causes a new supply in public transportation of the city so this model of presentation should stand versus urban trips demand.

The solutions followed in this research are offered in an algorithm to apply the conversion policies of the fleet namely in relation with the existent demand in the system. All the policies will be imported in emme/2 software to be analyzed by using available statistics and information to do a case study about LRT and bus lines of Tabriz city.

II. Prior Studies

Lampkin and Salmans have discussed the issues of determining the lines and the assignment of the fleet separately.[2]

Kocur and Hendrikson survey the planning of bus services from different aspects including the distance of the streets, scheduling the departure and the fare and then determine the optimum levels of these variables in several target functions.[3]

Ceder and Stern have made other attempts to improve the situation of the bus service by reducing the trips of unmanned buses, reducing the complexity of the bus network and fixing the timing of departure.[4]

Vijayaraghavan and Anantharamaiah by defining two types of new services and the change of the time of servicing of each line, reduced the size of its required fleet and investigated the issue of management of the network fleet in more detailed level.[5]

Leblank offers a method for designing the bus network that

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by the use of it, the frequency of each of the lines could be determined in a way that a balance is created between the maximum beneficiary of the lines and the minimum cost of the operation.[6]

Gao and the others have solved the problem of assignment the fleet in a public transportation network as a separate issue and solved it by the use of bi-level programming. [7]

III. Solution

By changing the number of fleet allocated to bus line headway of vehicles (bus) changes according to the blow relation. This equation is indicator of the relation between the number of fleet and the headway of vehicles in the line. [8]

$$headway = \frac{60}{fleet}$$

In which Headway is the time interval of the departure of the bus in line of the bus network per minute and fleet is the number of buses in line of the bus network.

The headway of the vehicles of bus line is related with the waiting time of the passengers in the station and also in the case that like this study, the optimal strategy method be used to assign the public trip demand to the public transportation network, the change in the headway of departure of the public vehicles causes changes in the waiting time in the stations of the network of public transportation system and the whole time of public trips(equal to sum of waiting, the time in the vehicle and the time of walking) and thereupon change in assignment of public trip demand to the network of public transportation system.[8]

Each of the public transportation systems namely bus and light rail transit have a separate offer system for urban trips demands.

Now if these public transit systems be designed and scheduled synthetically and integrated, they could have an offer surplus single planning for the trip applicants. In this research, we attempt to increase the capacity of transmission of the passengers of public multi-modal transportation.

Generally, by planning headway of public transportation vehicles (LRT and bus) to reduce the waiting time for the passengers and the whole trip time by increasing offer of public transportation systems, the desirability of system will be increased and there would be a good balance between demand and supply.

Considering the lack of flexibility of light rail transit system from variability in headway and number of fleet aspects, in order to reach an optimum structure, planning for the bus system has been taken into consideration. Also the waiting time of the passengers in common stations between lines has been developed as the optimizing indicator, considering the joint time period of passengers among combined systems.

In this study, the Frank Wolf method has been used for personal trip assignment, for public trip assignment the optimal strategy method and to choose the optimum combination, a dynamic model has been used. The above mentioned model as shown in figure (1) does the optimum fleet assignment to the bus network by receiving two entrance sets of supply and demand and using a choice logic and introduces the optimum bus fleet combination.

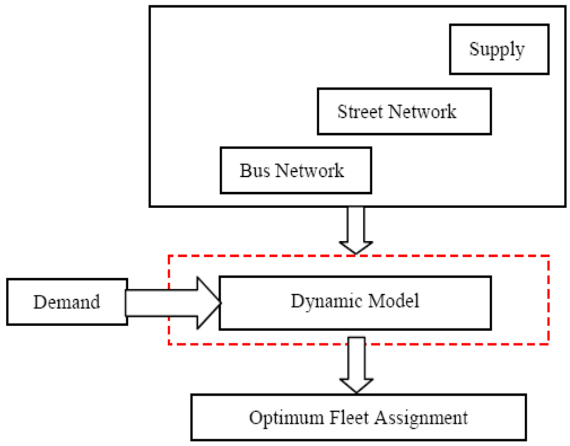

Fig. 1. Structure of model for choosing fleet optimum combination.

Operative procedure of model consists of an algorithm including 15 steps, which are explained below.

Step1: derivation of common stations among all the bus lines and LRT, called set B ($s \in B$)

Step2: allocating the digit of numbers of common stations between each bus line "l" and LRT lines to the examined bus line.

Stp3: choosing 15 bus lines which have the most common stations with LRT as the selected bus lines to apply the conversion policies of the fleet (the bus lines considered in the policy).

Step4: choosing the preliminary combination (the present status) of bus lines fleet as the preliminary reply of optimum combination of the fleet.

Step5: increasing considered bus lines fleet to reduce headway of bus in the lines and consequently reduce the waiting time of the passengers in each of the common stations between bus lines in the policy and LRT using increscent step that equal to 10% number of early fleet (present status).

Step6: the accomplishment of assignment phases of personal and public trips demand.

Step7: derivation of the number of passengers boarded in the common stations between all the bus lines and LRT.

Step8: derivation of the amount of headway of bus from the results of assignment in all the lines of bus network that their stations are joint with LRT.

$$h = \frac{1}{f} \qquad (l \in A_s)\,, s \in B$$

In which A_s is the set of all the bus lines passing from a supposed common station of bus line and LRT. And h is headway or reverse frequency of departure of buses in bus lines.

Step9: calculating the waiting time of each passenger in every one of the common stations between bus lines and LRT using the following equation which has come in the optimal strategy method part:

$$W(S_n^l) = \frac{\alpha}{\sum_{l \in As} f_l} \qquad \alpha = 0.5, (s \in B)$$

In which A_s the collection of all the bus lines passing from supposed common bus line and LRT, f_l, frequency or reverse the headway of buses in a bus line and $W(S_n^l)$, the waiting time in the specified common station of bus lines and rail transit, per minute for each passenger.[8]

Step10: computing the waiting time of passengers in each of the common stations between bus lines and light rail transit (LRT) using the beneath equation:

$$W(S_n^l) = \frac{W(S_n^l) \times b_s}{60} \qquad (l \in A_s), (s \in B)$$

In which $W(S_n^l)$, the waiting time of passengers in the specified common station of bus lines and LRT, is calculated per passenger - hour. [8]

Step11: calculating the sum of waiting time in all the common stations among bus lines and LRT.

Step12: derivation of the sum of waiting time in all the stations of bus network.

Step13: comparing the sum of waiting time of passengers computed in 11 and 12 steps with the same parameters get from the results of assignment with optimum combination of the fleet.

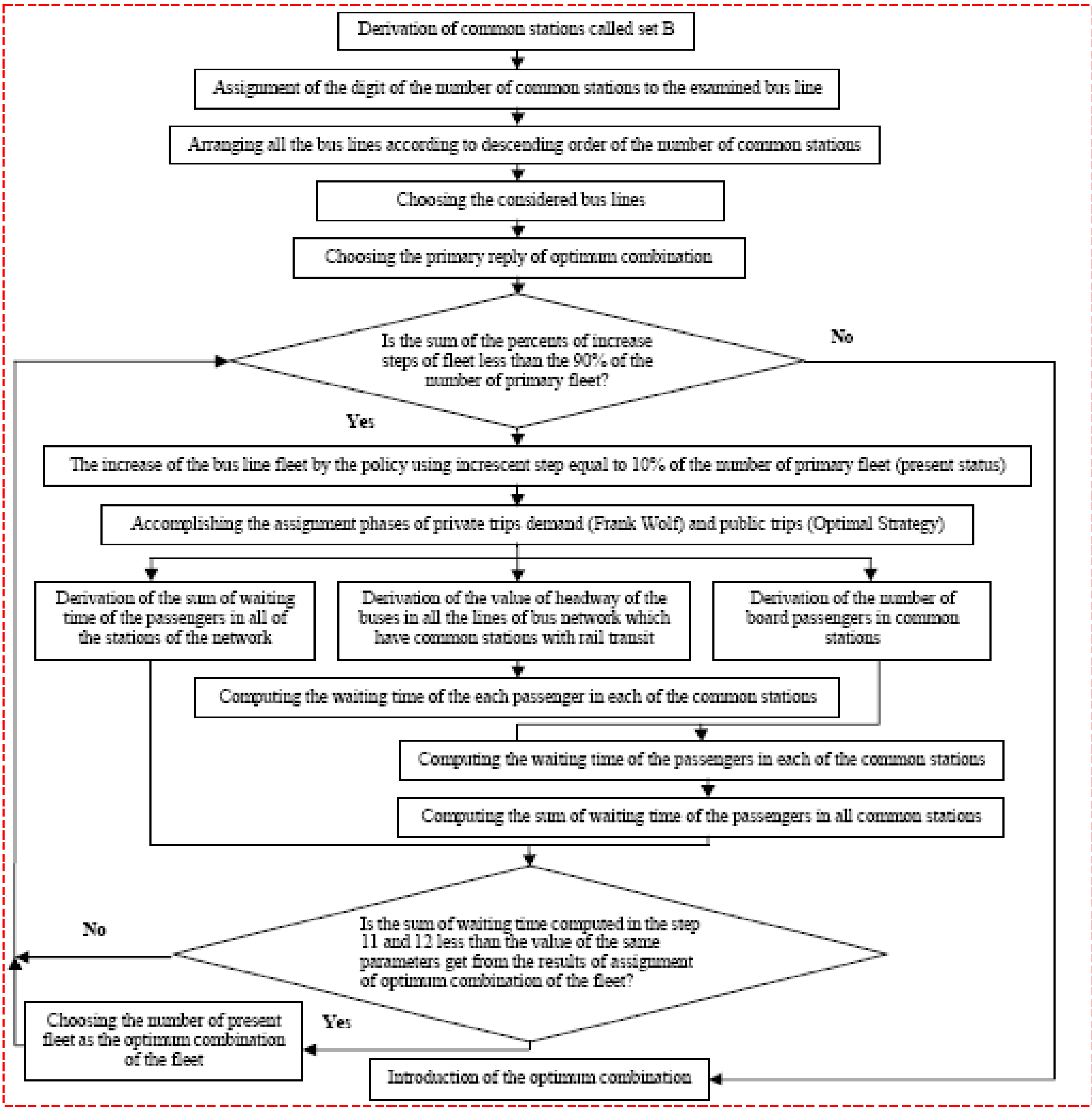

Fig. 2. algorithm used in the dynamic model.

Step14: if the sum of the waiting time of passengers computed in steps11 and 12 were less than the value of the same parameters get from the results of assignment of optimum combination of the fleet, choose the number of the fleet as the optimum combination of the fleet and then go to the step 5 but otherwise without changing optimum combination of the fleet go to step 5.

Step15: introduction of optimum combination of the fleet by completing the increscent steps up to 90% increase of the bus lines fleet in the policy toward early fleet (present status).

In the following, the algorithm used in the dynamic model has been displayed as a sample in fig. 2.

IV. Required Data

In this phase of research, procedure the solutions and the presented issues and studying suggested steps about in studying case has been tested.

A city must be selected as the case study which must have confirmed programs about utilizing the two bus and rail systems and also the informative bed and suitable statistics about demand models were available in the considered city. In this regard, Tabriz city selected as the case study. Noticing the procedure of the solution and suggested algorithm for implementing them in the case study of Tabriz, all the information about supply and demand models of the comprehensive study of Tabriz transport and traffic must be collected.

About demand, the quadruplet models of demand and their output and in the system of offer, the public transportation network including bus lines and light train, and also the network of private transportation pathways should be studied and their information should be collected completely. [9]

Another important issue in this regard was the data bank software emme/2 which moreover than the structure of Tabriz transportation and traffic information has been configured in it, it is required to implement the algorithm.

V. Implementing the Data in the Model and Analysis

According to the stated relations and 10 increase policy of bus line fleet which has been described in the Table I, the waiting time of the passengers in common stations per minute, the number of the passengers boarded the LRT at the common stations and also the waiting time of the passengers per person- hour in common stations has been computed.

Also, the waiting time of the passengers per minute has been computed according to $W(S_n^l)$ relation, and using the headway of the buses in the bus lines passing the common stations.

Headway of the buses has been computed in the emme/2 software via assignment of trip demand to the private and public (bus) network. Also the number of the passengers of LRT in the common stations has been computed by implementing the procedure of the assignment of public demand to the bus lines in the emme/2 software.

TABLE I: The Index of the Increasing the Specified Lines of the Fleet Policies and the Whole of the Bus Line Fleet.

number of policy	policy	Fleet number
0	Do nothing (2020 Demand + 2020 Network)	703
1	10% increase of the fleet (2020 Demand + 2020 Network)	719
2	20% increase of the fleet (2020 Demand + 2020 Network)	731
3	30% increase of the fleet (2020 Demand + 2020 Network)	741
4	40% increase of the fleet (2020 Demand + 2020 Network)	753
5	50% increase of the fleet (2020 Demand + 2020 Network)	766
6	60% increase of the fleet (2020 Demand + 2020 Network)	780
7	70% increase of the fleet (2020 Demand + 2020 Network)	795
8	80% increase of the fleet (2020 Demand + 2020 Network)	807
9	90% increase of the fleet (2020 Demand + 2020 Network)	819

The important point is that, by increasing the fleet bus lines that were considered in the policy in some of the common stations unlike the primal expectancy, the waiting time has increased per minute or in the different policies has swung. The reason is that in this study the fleet of some of the bus lines has been increased as the chosen lines for implementing the policy, while from each of the common stations several bus lines passes that some of these lines are not among the chosen lines selected for the policy. So this causes that the waiting time of the passengers in common stations become dependent on the headway of buses in lines other than the ones that have been chosen. Besides this, considering the commonness of a major part of bus network and the private network namely the stream of composed traffic of private vehicles and buses in the street, increase of the bus lines fleet could result in traffic increase and mass of passenger car equivalent transmission of the streets in the way of bus lines considered for the policy and as the trip time of the buses in the street is dependent on the speed (the departure time) the traffic stream of other vehicles (private), so by increasing the fleet, the time of departure in some of the arcs(streets) of the network increases.

Noticing the linkage of public transportation network and private vehicles and also the reciprocal influence of these two parts of urban transportation system on each other, the information of the measure of function of private vehicles on the basis of passenger car equivalent and public (bus) in a peak hour has been displayed in figures. [10]

Because of the reciprocal influence in the section of urban transportation system it is apparent from the diagrams that by increasing the fleet bus lines, the spent time of passenger car equivalent of the network indicates a swing. The omitted time of the network is indicator of the amount of expenses imposed to the users of personal vehicles in the network.

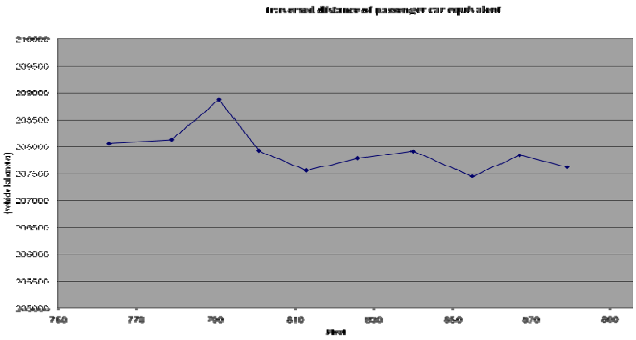

Fig. 3. Traversed distance of passenger car equivalent.

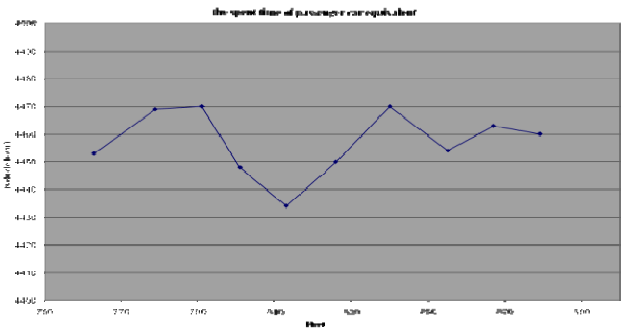

Fig. 4. The spent time of passenger car equivalent.

In Fig. 3 that the traversed distance of network has been displayed, swing can be seen. This swing emerged because by increasing the fleet of bus lines in the policy, the transit mass of arcs and consequently trip time of network paths changes which causes the change in the shortest time paths between some of the origins-destinations of the trips. This causes that the users of private vehicles use other paths to make their trips from the origin to the destination.

In the following figures, the information of the users and the function of public transit network in a peak hour for 10 fleet increase policies have been displayed.

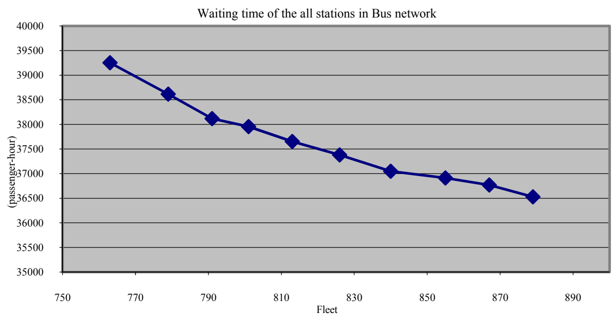

Fig. 5. Waiting time in all the stations of bus network.

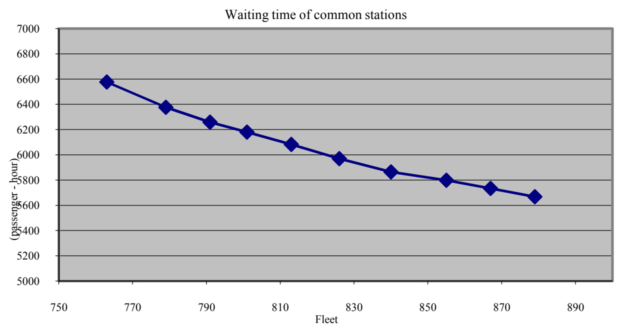

Fig. 6. Waiting time in the chosen stations(passenger-hour).

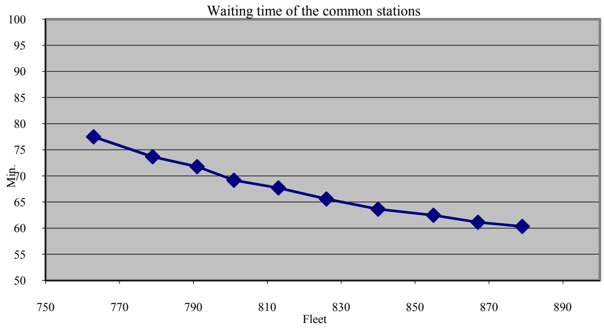

Fig. 7. The waiting time in chosen stations(minute).

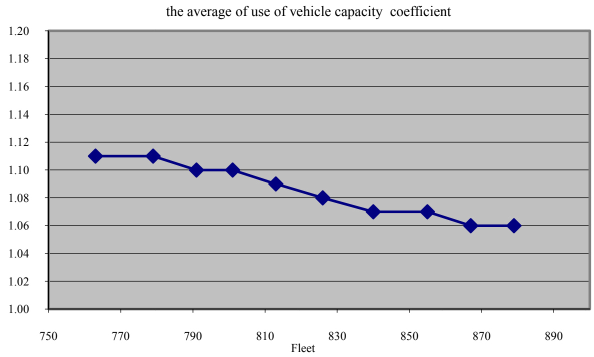

Fig. 8. The average of use of vehicle capacity coefficient.

VI. Specifying the Optimum Combination of the Bus Fleet

For the below reasons the policy number 4 (increasing 40% fleet of bus lines in the extent of policy) determined and introduced as the dominant policy and the optimum combination of the bus fleet.

First reason: the policy number 4 resulted in a significant decrease in the spent time of network and acquiring the least measure of spent time in the network.

Second reason: the number 4 policy in the descending procedure of different waiting times of passengers of public transportation system from number zero policy to number 9 has the middle rank and considering that it imposes the mean cost of purchase of the fleet to the operator of the system, it has a logical position. This means that in the case of equality of the benefit of this policy with the number 9 policy, because of the 90% increase and imposing the utmost expense of purchase of the fleet to the operator of the system in contest with number 4 policy is rejected.

The third reason: the number 4 policy after the number 7 policy has the least measure of traversed distance in the network, which causes the reduction of functional expenses of personal vehicles in the network.

The point is that in the scale of the policies of this study the parameters of public traversed distance (vehicle-kilometer) and the spent public time (vehicle-hour), cannot be used because these two parameters are completely dependent on the number of public vehicles namely the bus fleet and by increasing the number of policy and as a result increasing the bus lines fleet in the policy, they just display increase.

VII. Conclusion

In the public transportation studies, the network and structure of public transportation systems could be surveyed and designed in two conditions. In the first condition each of the systems be studied separately and the demand of trip is designed for each of them. However, in the second condition, which has been used in the majority of the present studies, all of the systems beside each other are designed in combination and integrated. It means that each of the systems for instance LRT and bus have common stations, which the passengers could shift between these two systems. In this condition, the offer system has more desirable situation and more benefit will be achieved from the capacity of public transportation fleet.

Nevertheless, the issue that has been analyzed in this research is the scheduling and design of the fleet of each of the multi-modal public transportation systems, LRT and bus lines in the condition of a case study to better impart from the capacity of movement. This timetable has been presented on the basis of the optimizing procedure of waiting time in the common stations between the composed systems. In the figures, the number of the fleet and the sum of headways of bus lines in the do nothing status (the number zero policy) and the superior policy (number 4 policy) has been displayed.

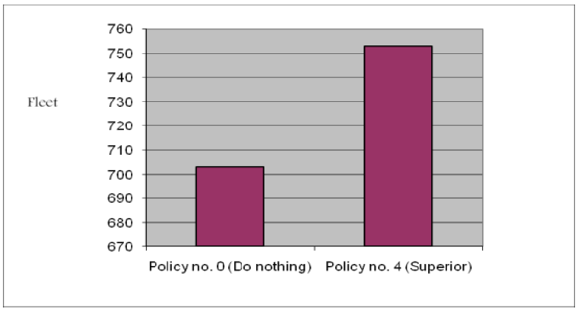

Fig. 9. The number of fleet (do nothing , superior policy).

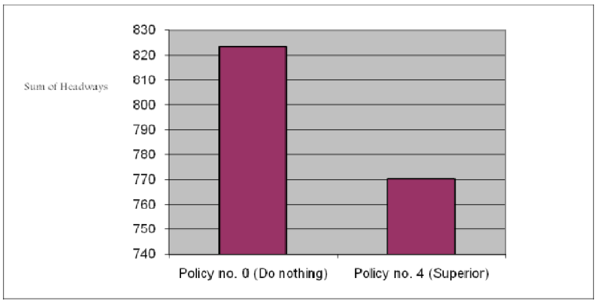

Fig. 10. The sum of headways (do nothing , superior policy).

Choosing the bus lines related to the policy in the dynamic model is the primary and a basic step in the traffic analysis of the urban transportation network and the change of the function of the network and consequently specifying the optimum composition of the bus fleet that in this study, these lines has been chosen by the criterion of the most interference with the lines of light rail transit (the maximum number of common stations).

It is suggested to use other criterions like the measure of impartation of the chosen lines from the movement of passengers. In this research because of the interference of effective bus lines of Tabriz city in some limited stations, the possibility of use of this criterion does not seem logical.

Increase of the fleet of all the bus lines considered in the policy in coordinated steps (10%, 20 %,…) was a method that was used in this research. It is suggested that the measure of bus line fleet increases of the policy in every step, be related to the results of transportation system analysis in the previous steps and this increase be accomplished intelligently.

The similar of this research can be accomplished with other goals like reducing the functional expenses of the network including functional expenses of both parts of urban transportation system (personal,public), or reducing the air pollution.

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