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A New Approach in Designing the Transportation Path of Urban Buses Using GIS (a case study of district no. 10 of Tehran)

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Abstract: Urban bus system is considered as one the most important public transportation systems. In designing such a system, it is needed that several objectives -some of which are contradictory - to be considered simultaneously. These objectives cause doing the design to face some problems. For an example, the routs which are designed for decreasing trip time may not have the highest accessibility. That is the reason why we need to consider different issues simultaneously to reach the optimal design. In this article, using GIS capabilities which are extant in its softwares , a new model for the optimal designing of the urban buses network is presented.

The above mentioned model is founded considering several main objectives. For example, we can refer to opitmalization of number of travellers and also the decrease in trip time. The rest of the objectives are discussed in the third part of this article. The presented model is based on the matrix of urban blocks distribution, the method of its extraction is explained in this article. After extracting the matrix of distribution of trip between urban blocks, and allotting it to the urban paths, we have used the capabilities of GIS network to design the lines. Using this method, we can design of the urban buses' path by considering several main objectives simultaneously.

Keyword: GIS, demand for travelling, weighed graph, location finding, trip time.

INTRODUCTION

Transportation is one the infrastructures of the country and determines different levels of people's and goods' access from one place to another (Kuswar (et al) 2006).Transportation system is one of the factors which indicates the development level of one country. Information-location systems have enormous capabilities in the field of management and optimal designing of facilities such as transportation. One of such capabilities is the ability to analyze the network such as calculating the shortest path in the information-location systems. This article's objective is to present a new method to design transportation path for urban buses using GIS. The structure of the article to reach this objective is made as explained. In the second part of this article, there will be a review of extant researches along with stating some of their deficiencies. One of such deficiencies is that in the previous researches, the most emphasis has been on the level of access to the network, while designing the public transportation systems, various other issues have to be attended too. In this part, different objectives which in the proposed model of this research have been considered are explained.

In the fourth part, a method for predicting demands for travelling between urban blocks is presented. To do so, it will be stated in this article that how we can first predict the trips for each of the blocks and then considering the predicted level of trips for each blocks and the distance between them, the distribution of trips between them will be discussed. In the fifth part, there is presented a method for weighing the manes of urban roads network to be able to use the capabilities of the network GIS. The presented method uses the matrix of distribution of trip from the previous phase and also the time for trip from the urban network manes as the input. In this part, the capabilities of GIS network for designing transpiration path of urban buses will be discussed. This will be done on the weighed network gained from the previous phase. In the sixth part, for better understanding and the model testing, one example in which the proposed method is performed will be explained.

The Researches Already Done in Designing the Transportation Systems

The researches done on designing the public transportation system were mostly based on the traffic analysis. In these researches, the planning of transportation, traffic and performing the models for predicting trip demands, requires dividing the region under study to separate regions and units. In this case, the planner will be able to relate the information on activitiess, trips and transportation to the physical places extant in the region under study.(Meyer and Miller,2001).Therefore, in these studies, the traffic analysis zones are considered to be one necessary input for the transportation planning. The origin and destination of trip will be determined using these traffic analysis zones. The traffic analysis zones need to be signified following several criteria that are given below in order to be able to show the trip information correctly (YOU (et al.)1997, O'Neill, 1991):

all the economic and social specification of the regions
the minimized number of trips done within a region and the maximized number of trips done between the regions.
the traffic analysis zone has to be in vicinity of one another.
regional compressionability of the regions.
similarity in the trips and their distribution

The size of traffic analysis zones has to be chosen in a way that only 10 to 15 percent of the trip done in them is within one region(Meyer and Miller,2001).Designing the traffic analysis regions, it is tried that such regions include the similar urban activities, in the sense that all the residential

,business or industrial regions have to be designed in a way that they have almost similar specifications(Ortuzar(at al.) 2006,Banister 2002)as it is already stated, designing the public transportation system ,we have always used the traffic analysis zone which indicate the regional potential demand. For example, in (Rairez and Seneviratne, 1996), using statistical data, a model is developed for designing a new transportation path which will help reduce the trip distance to the best and increase the number of travellers to the best, but some of the weak points and complications of the research done are as follow:

.In most of the researches which were referred to in the above and other researches, the capabilities of GIS are used in a limited way , while the role of GIS can be more useful and efficient in this issue.

.Though the local collected data are used extensively in the analysis and planning of transportation, but it seems that these data has had different effects on the results of modeling (Miller, 1999).The effects of the collection of data are not studied usually in most of transportation studies and it is supposed that collected and used data have enough details for producing the exact result and correct modeling. The issue of producing the appropriate fundamental local units to analyze and model is not only limited to transportation model, but also has been an important research topic in the science of local information for long years.

.The limits of traffic analysis regions are often based on the parameters and quality criteria and no exact limits can be extracted from them.

Considering the issues and weak points in the extant methods in designing transportation systems that have been pointed out to, one method is presented in this article which is based on GIS capabilities and is almost empty of above mentioned issues.

Considered Objectives and Criteria in Designing the Transpiration System of Urban Buses

The objectives which are considered for designing transportation system of urban buses in this article are as follow:

.Maximizing the urban coverage by the transportation system: To do this, we need to develop the bus path around the city in a way that the distance of each location to the nearest station, won't be more than a given limit. To reach this goal, designing of system should be done in a way that almost all the city blocks are covered.

.Maximizing the capacity of transferring people by each bus: To do this, it is required that the buses' path to be designed in way that it will pass through centers to which there are many demands to travel.

Decreasing trip time which includes the following:

a. Minimizing the time for accessing the nearest bus station: This criterion is evaluated with the same maximization of the urban coverage level of the transportation system.

b. Minimizing the trip time by choosing the optimal path for bus movement: Choosing the optimal path with the least trip time requires having the length of each link and also traffic information in any of them.

.Decreasing the number of mounting and dismounting a traveller: In other words, the paths should be designed in a way that travellers pay the least money for travelling from one place to another (Vuchie, 2005).To do this, we also need to design buses' path based on demands for travelling around the city.

Predicting the Demand for Travelling

In this section, the method is presented for predicting the trip demand between the city blocks. After preparing needed data in GIS, the prediction of trip will be done for each of the blocks. Usually the different trip models are developed considering different objectives (Wilmot, 1995).Then, considering the amount of predicted trips for each of the blocks and the distance between them, the distribution of trip between them will be done.

Trip Generation and Absorption

The objective of this section is to present a solution for modeling generation and absorption of trip in each of the city blocks based on different trip goals. The models for the generation and absorption of trip use the known relations between the number of trips and statistical information to predict the number of trips to or from the blocks. The number of trips to and from one region depends on usage of lands in that region and the socio-economic specifications of the travel generators (Ortuzar (et al) 2006).Using the capabilities of GIS in the modeling stage of trip generation can help the planners and decision makers of transportation sphere considerably(Karstrm and Berglund,1999).Arbani and his co-workers have done the modeling of trip distribution using the phase logic and the effective parameters in it(Arbani, Rabii and Amani-2996).The model offered by them is based on a phase operator and four functions which include: the number of family members, car ownership, income and household structure as the input functions. Usually this model –as a result of strength and simplicity of regression analysis-is used to model for trip generation and absorption (Papacostas and Prevedouros, 2001, Banister, 2002).In this research too, the regression method of multivariables have been used to generate and absorb trip. The method used is a mathematical method in which all the variables are the incidental variables with normal distribution. The general form of a regression model is as the equation (1):

$$Y = a_0 + a_1 x_1 + a_2 x_2 + \ldots + a_n x_n$$

In this equation, y is the dependent variable, xi is the independent variable, ais are the parameters of model that are first evaluated in the model. The dependent variable is the number of the generated trips from regions or absorbed to them for each of the travel objectives and each of the independent parameters in these models is indicator of each of the specification of the regions. To evaluate the model parameters, the real data related to the number of generated and absorbed travels and the related information to each of the effective specifications on the amount of trip generation and absorption are used (Wilmot, 1995).

But one basic problem in creating the regression equation is using specifications which are indicating the number of generated or absorbed trip in the best possible form; because using all of the specifications in one model is a difficult voluminous work that cannot be done. Also, this way there is needed a voluminous amount of input information, the gathering of which is a difficult and even impossible task. That is the reason why to reach the shortest and most suitable equation for the linear value in making the models, step by step method is used. In this method, first the correlation level of R2 of independent parameters in estimating the dependent parameter is evaluated in order to determine which independent parameter has the highest level of correlation to the dependent parameter. In the next stage, this process will be continued by increasing each of other dependent parameters than the primary parameter in the form of available linear double variable equation and in each stage, the level of gained R2 will be calculated and compared to the its previous amount. This process will be continued till the determination of the best secondary parameter; it will be in a way that in the valuable linear equation gained from the primary parameter in comparison to other double variable combinations, the highest amount of R2 is small and negligible. The extant parameters in the linear equation gained from this method will be the most important and effective parameters in generation and absorbing trips.

This way, a separate model is gained for each of the trip goals. As the objective of this research is to design the network for public transportation path for the peak hours and as the work and education trips have the highest number at the peak hours, only these trips are considered as the trip demand between the blocks. These models along with the amount of their coefficient correlation are brought in the following:

The Trip Generation Models:
The work trips:

$$J^{w}_{i} = 0.565*VP_i*RE_i + 1.112=RE_i \quad , \quad R^2 = 95.7\%$$

.The education trips

$$J^{s}_{i} = 1.473*VP_i*RSt_i + 0.825*RStu_i \quad , \quad R^2 = 86.3\%$$

Travel Absorptrion Models
Work trips:

$$J^{w}_{j} = 1.627*E_j + 2.414*Shp_j + 5710*DM_j \quad , \quad R^2 = 86.1\%$$

.Education Trip:

$$J^{s}_{j} = 1.231*St_j + 0.762*Stu_j + 2176*DU_j \quad , \quad R^2 = 80.5\%$$

In which:
VP_i: The personal car ownership in the region I per capita
RE_i: the number of the employed [people residing in the region i
E_i: the number of the staff in the job units extant in the region i
RSt_i: the number of students residing in the region i
St_i: the number of student of education units extant in the region i
$RStu_i$: the number of university students residing in the region i
Stu_i: the number of university student in the high education units of the region i
Shp_i: the number of business units extant in the region i
DM_i: the variable for the market in the region i
DU_i: the variable related to big universities extant in the region i

We have to consider that besides the effective main factors in generation and absorption trips, some figurative variables are also put for some special regions. All of these variables start with letter D and their amount for considered regions is one and for other regions is zero. The reason for choosing these variables is to adjust more the amount of generation and absorption of trips to the sampling done. Using the above relations, we can gain the amount of generation and absorption of trips for each of the urban blocks. We also have to consider that these models are used only to predict the going trips. Therefore, to evaluate the number of the whole of generated or absorbed travels of each region, it is enough to sum up generation and absorption amount of trips of that region; the reason for that is that each region has as much absorption for going trip as it has for generation of return trip.

Trip Distribution

After it was explained how to reach the amount of trip generation and absorption for each of the urban blocks, the objective of this section is to calculate the distribution of the generated trips among the urban blocks. The trip distribution is often based on the absorption model, but using other models is also common more or less. In the absorption models, we can use different parameters such as distance, time or the expenditure as the resistance factors against travelling. In this research, for not having information related to traffic and the movement speed on the roads, only distance in the road networks is considered as the resistance factor. To calculate distance between urban blocks, first, using the software ArcGIS 9.1, their gravity centers as the representative points for the generation and absorption of trips are determined and then the nearest extant path to those points is recognized and this way the shortest way between blocks is calculated. The length of the shortest calculated distance and also the distance between gravity centers and the nearest passageway as the distance between blocks plays the role of resistance factor against trip. Finally, a matrix will be made, the number of its line and columns is equal to the number of blocks and in fact, it signifies the distance between blocks of origin and destination.

After determining the matrix of distance, we have to signify an appropriate resistance function for each of the objectives of trip. On the whole, this function states that as the resistance level (including: time, expenditure, trip distance and …) increases between two regions, the travellers will show less willingness to travel to those areas. Though, in the absorption model, we can use the simple reverse resistance (or resistance square), but the experimentally, it is known that more complex functions

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have a higher functionality. The most used resistance functions in the absorption model are the chart, power and Gama functions (Ortuzar (et al), 2006).In this research, the Gama function with the overall formation of the equation (6) is used:

$$F(d_{ij}) = a * d^{-d}_{ij} * e^{-c(d_{ij})} \quad , a,b,c, > 0$$

This function -as a result of having chart and power functions - has more flexibility to be used in the absorption model for trip distribution. This is how a separate Gama function is developed to distribute the trip for each of travel objectives. The reason for the resistance function to be different for each of the trip objectives is that the willingness level of people to do trips of different length changes considering the objectives of trip.

But before using the resistance function of Gama in the absorption model, we have to calibrate it using the extant sampling data. In fact, the main objective for calibration of the absorption model is to estimate the parameters of the resistance function. After calibration, the resistance functions will be gained according to trip objectives and by using them between pair regions, a certain figure will be reached for each of the trip objectives and which is generally known as the friction level between the known regions and will be saved in a matrix known as the friction matrix. The resistance function of Gama for distributing work and education trip is as follows:

.resistance function of Gama for distributing work trips:

$$F(d_{ij}) = 12103 * d_{ij}^{-1.389} * e^{-0.000602(d_{ij})}$$

.the resistance function of Gama for distributing education trips:

$$F(d_{ij}) = 4854 * d_{ij}^{-2.076} * e^{-0.000925(dij)}$$

Finally, for each of trip objectives, distributing trips between urban blocks will be done separately; it will be in a way that the total of each line of matrix for the trip distribution is equal to the trip generation and the total of each column is equal to total of the predicted travel in the region where trip is generated. To do this, the dual balance of distributing trip (conditioned to generation and absorption) is used. This way, for each of the trip objectives, one separate matrix for distributing trip will be gained in which the number of lines and columns is equal to the number of statistical blocks used. In the case study done in the section 6, one sample of such calculated matrix is shown.

Weighing Manes Based on Demands for Travelling and Time Trip

Before stating how the weighing of network manes should be done, a short explanation should be given about the graphs and theories related to it:

The concept of graph was offered and gradually developed in the year 1735 by Oiler suggesting a solution for the issues of the Koniksberg bridges (Barnet, 2005, Ore, 1990).In the world around us, there are many states and situations which can be modeled by the collection of knots and manes. Graph 6G includes two functions (N, E) in which N is a definite and solid collection of knobs and E includes pair relations between knots. N, is the collection of knots in the graph and E is the collection of manes in the graph (Bloundy and Murthy, 1999).

Oriented Graph

Oriented graph is a graph to each of its manes, one direction is allotted. In cases such as the network analysis, it is required to use the oriented graphs in order to show the direction of authorized movements in the streets (manes) in order to model the real world (Keshtiarast (et al.),2006).

Weighed Graph

Weighed graph is a graph to each of its manes, one weight is attributed. In the network analyses, this weight can indicate the distance between two heads of transportation time from the graph mane in the network and etc.

The Path

Path P is a trail from heads <V1,V2,V3,…Vn> in a way that the pair (Vi,Vi +1) is a member of the collection E (manes).If the graph is weighed, the shortest distance from Vi to Vj is the path that sum total of its manes' weight is the least possible amount in comparison to other paths from Vi to Vj.(between two points of each graph, there are many possible paths)(Keshtiarast (et al.),2006).

Algorithm to Calculate the Shortest Oossible Path

The issue of the shortest possible path has always been one of the most important issues in the location analysis in the transportation and also service system for the original location. With ever increasing development of such systems and considering the mathematical models and network structures, different algorithms have been presented to help optimal finding of paths having the parameters, specifications and network structure in view. Considering the variety of the issues related to location finding from the viewpoint of graph structure and parameters ,there has never been an optimal algorithm for all the location finding issue and one algorithm- apportion to each issue -can give the best result. Algorithms for location finding are divided into two main groups of matrix algorithms and tree-structure algorithms (Preygel, 1999).

Matrix algorithms find the shortest distance between pair heads in the network using repeated operation. The base for these algorithms is that they consider network as a matrix. But the tree-structure algorithms find the shortest distance from the origin head to other heads. In such algorithms, there will be made a tree of the shortest paths with the branches spread from the origin. The tree-structure algorithms include digestra algorithm (Cormen (et al.), 2001), Bellman Ford (Dechter and Pearl, 1985) and matrix algorithm include Floyd-Warshall and Johnson algorithm (Gosper, 1998).

In the issue of designing the transportation path of the urban buses, it is required that the weighing of network manes be done based on the designing objectives. To do so, some stages have to be considered:

Stage 1) In the first stage, a network of all street that have the necessary standards for urban buses movements will be made and then the related graph to this network will be extracted; in such a graph, the manes are the same as network lines and the knots are the connection points between lines(crossroads and …).

Stage 2) In this stage, to each of the graph manes, one weight will be attributed based on the travel time in it and also the demand level for the trips between its blocks. The final weight of each mane will be calculated through equation 8:

$$We_i = \frac{Tei}{Cei}$$

In this equation, W_e: mane's weight, C_{ei} , e_i: the demand level for trip in the mane ei that will be gained through the sum total of predicted trip generation and absorption for the blocks around it, and Tei is the time for transporting from mane e_i.

As it has already been stated, in network analyses, the best path will be chosen in a way that the sum total of the manes' weight of that path will be minimized. In other words, the mane with less weight is preferred to the mane with more weight. That is the reason why the time for transporting from mane (T) and (C) should be placed as the numerator and denominator respectively in order to gain the final weight of each mane.

Stage 3) After the weight of each of network manes has been determined considering the designing objectives, time comes for the extraction of the final network of the buses' path and the appropriate manes should be chosen from the total of network manes. This work can be done using the capability of software network ArcGIS 9.1. To do this, first two blocks which have the highest distribution of trip between them ,will be chosen as the origin and destination of trip and an obstacle will be put on the manes connected to the blocks which have no trip from the origin so that the path does not pass through them. Then, using the analysis of the shortest path, the best path between them will be extracted having the related weights to the network manes in view. Doing this, besides the fact that the issue of trip time at least between the origin and destinations of trip is considered, the path will pass through the manes that have the highest demand of trip from origin to them. In the next phase, two blocks with the maximum distribution of next trip will enter and the operation of path finding will be repeated between them. This process will continue till the level of trips between blocks reaches a threshold and the buses' path network almost covers the whole city. Certainly, it is not needed that the operation of location finding between all the blocks be done separately in order to cover the whole city, because in each stage of finding the path between two blocks, the demand for trip to some other blocks is also obviated. In the following, all the mentioned stages will be explained through a case study in which the presented method in this research is explained.

Case Study

In this section, the method of practicing the presented method in this research is explained in a case study. In order to this, part of the district no.10 of Tehran city is chosen as the study district (fig.1). The district is almost in the form of square and relative dimensions of 2 kilometers.

To do this research, the software ArcGIS 9.1 is used. The method of using it is explained in the figure 1.

Considering the mentioned stages in the figure 1, as explained in the figure 2, the network is generated from all the streets that have the required standards for the movements of urban buses in them and then the related graph will be extracted in which the manes are the same as the network lines and knots are the connection points of lines.

In the following, using the method which has been mentioned in the stage 3, the demand level for the trip between urban blocks will be predicted.

To do so, first using the generation and absorption model of trip, the number of trips related to each block will be gained. The region under study includes 482 blocks, for each of which the sum total of trip generation and absorption has to be calculated based the presented models.

Table (1) shows the done calculation for each of 10 blocks of the whole regions separately.

After the generation and absorption level of trip for each of the blocks is gained, we have to deal with destruction of trips between blocks. As was stated in the stage 3, this work is done using the absorption model. Table (2) shows the distribution of trips between the blocks presented in the table (1).

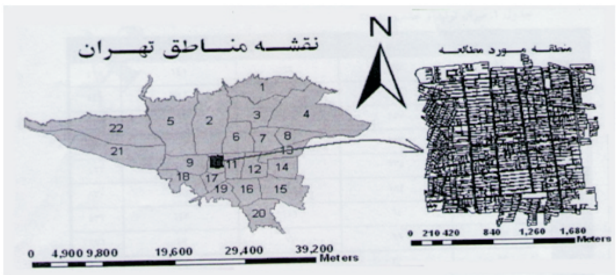


Fig.1 the region under study (district no.10 in Tehran)

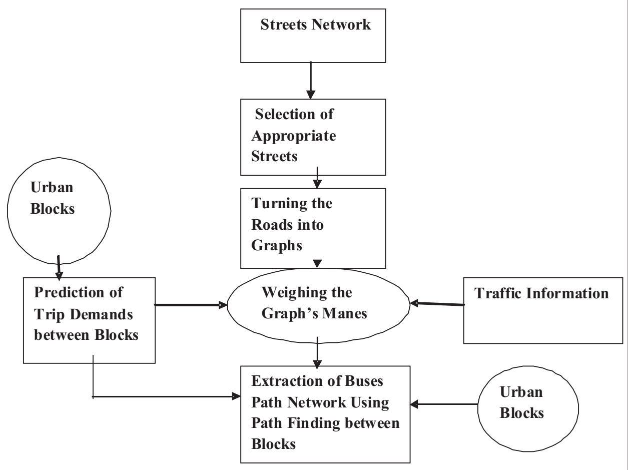
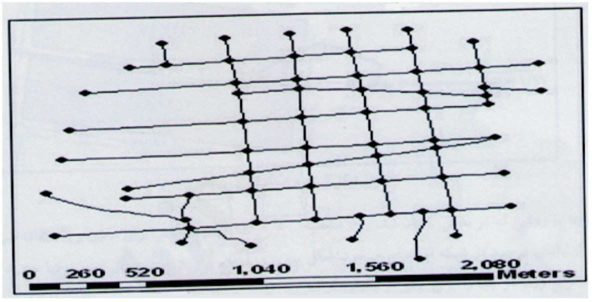


Figure 1.The Introduced Model for Designing Transportation System of Urban Buses



Extraction of Appropriate Streets and Turning Them into Graphs

Sum Total	Education Trips Absorption	Work Trips Absorption	Education Trips Generation	Work Trips Generation	Blocks
415	141	66	117	92	1
549	121	130	149	148	2
713	161	208	157	187	3
733	113	219	183	218	4
422	70	104	135	113	5
830	250	259	184	137	6
437	143	101	64	129	7
272	47	77	66	83	8
226	46	80	31	99	9
255	71	49	31	103	10
3980	885	670	1117	1308	جمع

Table 1.The Generation and Absorption Level of Trips for 10 Blocks in the Region under Study according to Trip Objectives

Sum Total	10	9	8	7	6	5	4	3	2	1	to	from
209	2	2	3	11	24	3	28	47	7	83		1
297	13	9	2	15	66	28	9	33	104	16		2
344	3	4	6	31	58	5	42	136	18	41		3
401	3	3	42	42	44	4	177	49	8	28		4
247	9	14	2	9	38	95	7	17	47	8		5
321	7	6	6	38	168	9	10	41	24	11		6
193	2	2	12	64	48	4	20	24	10	8		7
148	1	1	48	25	18	1	33	12	4	5		8
130	25	42	1	3	19	17	3	4	14	3		9
135	55	14	1	5	24	8	3	5	16	3		10
2426	120	96	123	224	509	174	332	369	252	206		جمع

In the following, the appropriate weight for each of the manes extant in the network will be extracted having the method stated in the section 4 in view. Figure (3) shows the method of extracting the weight of each mane for one of the graph's manes. In this figure, the numbers written in the blocks shows the sum total of their trip generation and absorption (the real numbers are not rounded and are gained from the explained models in the section 4) and the numbers written in the manes show time for transportation through them. Of course it has to be mentioned that in this case study, their trip time is simulated as the real time for trip in each mane was not available.

In the end, using the presented method in the third phase of section 4, the buses' path network will be extracted. This is done using the matrix for trip distribution between blocks and location finding in the graph which was extracted from the previous stage. Path finding is done through analysis of the shortest path using the software ArcGIS. This software uses digestra algorithm for path finding. The threshold for finishing path finding between blocks is number 5, in the sense that path finding will be done between blocks which has trip level of more than number 5. Figure (4) shows the final network of buses' path. In this figure, the lines which are marked by the dark black color indicate paths through which the buses' line should pass.

Finally, considering the case study done, we can say that GIS and its tools can play an important role in doing the complex calculation and creating more precision in designing the urban transportation buses' path. As was observed, using the capabilities of sofwares network of GIS in designing the transportation path of the buses, we can consider different objectives alongside one another.

CONCLUSIONS AND RECOMMENDATIONS

As was stated, designing the movement path of urban buses is one of the most important sections for designing the public transportation systems. In this research, to design the movement path of the urban buses, a method was presented that can be a suitable solution for simultaneous dealing with several objectives for designing the transportation systems .These objectives were explained in the third section of the article. As was seen, in this research, the urban blocks and information related to it were used as the traffic analysis regions so that we can simultaneously consider the issue of the urbane coverage of transpiration network and the issue of maximizing the transportation of travellers. This way, we can say that in this method, contrary to other extant methods for designing the transportation network which are completely dependent on the precision of determining traffic analysis regions, we can use the urban blocks which have been signified previously as the traffic analysis regions.

To model the trip generation and absorption of the urban blocks, multi-variable regression method was used as the regression analysis is strong and simple and also the absorption model with the resistance function of Gama was used to distribute the trip between blocks. The capabilities of the softwares network of GIS were used to deal simultaneously with all the designing objectives. The network analysis in GIS is done according to the graph theories and principles. In this research work, it was shown that in order to deal with all the objectives of designing objectives, the weight allotted to the graphs' manes in the urban paths' network has to be calculated having the trip time and the demand level between urban blocks in view. The case study done in this regard shows very useful results considering different objectives in designing and using the capabilities of GIS.

Finally, the following cases will be recommended as the continuation of this research work:

.After signifying the buses' movement paths network which was dealt with in this article, we have to separate the lines and signify the number of the appropriate line for the extracted network that requires signifying the origins and destinations and should be based on the information related to trip demand between the blocks.

.After marking and separating the lines, it is required that for each line- considering the trip demand level, trip length, path traffic and … - the appropriate frequency for the buses' movement has to be designed and then regarding the designed frequency, the adequate number of buses be allotted to it. It seems that some analyses such as Fourier and Mojek which take an information signal in the argoman space (for example, time or place) to the frequency space, can be used in this section.

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