An Alternative Approach to Centroids and Connectors Pattern: Random Intra-Zonal Travel Time

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Abstract

In traditional traffic assignment procedure, each traffic analysis zone is represented by one point in its geometric center which is connected to the network by several connectors. Results of studies show that different connector patterns would result up to 10% change in estimated volume and up to 20% change in total travel time. Also the different patterns of connectors can change the priority of network development projects. Because of numerous possible scenarios for connection patterns, finding the optimum pattern is very difficult. The main goal of this research is proposing a substitute approach and proper solution algorithms to increase the accuracy of traffic assignment results. In this approach, the travel time inside the zone is considered as a random variable and is used in traffic assignment process. At first, all possible candidate nodes in each zone are selected and then between each pair of these nodes in different zones, the shortest path is determined. After that, the share of each route is estimated using discrete choice models and then share of them from demand is calculated. The proposed approach is tested using a real-size network with two route choice models of Logit and Probit. The results show significant changes in total network indexes (15%) and the average error in estimating of links volumes, has been reduced by 20%. Although the calculation time may increase 10 times than before, the proposed approach leads the traffic assignment results more accurate and close to real observed links volume.

Keywords: Centroid, connector, random access time, probability density function of intra-zonal travel time, Logit and Probit Models

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1. Introduction

Traffic assignment means to estimate link volumes based on the route selection of passengers. The procedure of assigning demand has different models and methods. By assigning traffic demand to network, an estimation of traffic volumes is made and the network's performance could be assessed. This procedure is the last step of urban transportation studies and is the most important part of that. As a result of its importance, selecting best model, presenting more adequate procedures, and providing more realistic results have been always attractive to transportation researchers.

In assignment procedure (in any methods) there is a need to establish appropriate connection between supply (transportation network) and demand (trip generation points) features. In traditional traffic assignment procedure, traffic analysis zones (TAZ) turn into points (centroids) in geometric center of zones and are linked to main nodes and links of network with virtual links (connector). This approach may lead to a major error in traffic assignment results. The main goal of this study is improving the accuracy of traffic assignment results by eliminating centroids and connectors and proposing alternative approach.

In the following sections, the literature review and then the methodology of research is described and the characteristics of the proposed alternative approach for connection pattern is presented. Then, using the Qazvin network as a case study, the different assignment results using the proposed approach are presented and compared with traditional approach. Finally, based on the results, discussions and conclusions are done.

2. Literature Review

The TAZ centroid must be proper representative of the zone. This point should be the best representative of all land uses, origin of produced trips and the destination of attracted trips of zone. There are different ways to select the proper centroid location. In urban traffic zones, centroid is a point with the maximum demand, which is in practice the geometric center of residential or commercial of land uses. But, in most cases, this approach cannot be implemented since there are several major attraction/production points.

In the study by Chang et al. four methods for choosing centroid location have been compared (1-Geometric center of zone, 2-Geometric center of non-residence land uses, 3-Geometric center of residence land uses weighted by their population and 4-Geometric center of residence land uses weighted by their household numbers). As a result in this study for big zones weighted average methods has better result but for small zones this results isn't desirable [Chang et al. 2002].

Martinez et al. showed that centroid could be set through production and attraction points of zone that are found by OD surveying. This study presents a regression relation to estimate production and attraction density in traffic zones of Lisbon. In this method the points that create maximum trip density are chosen as centroid and zone gets expanded around it. According to this approach the distance between centroid and major production and attraction points are decreased. This method needs so much of field data that usually aren't accessible for researchers [Martinez et al. 2007, 2010].

In available transportation planning software, connectors could be created manually or automatically. For example in auto mode of Cube software two conditions are assumed: 1-Closer nodes to centroid have higher priority for connection, 2-Links that made small angles together have lower priority. By considering these two conditions, centroids will be connected to closer nodes in a more scattered way.

In Friedrich's study three systematic methods are provided to choose how to connect a centroid to main network. The results presented in that study are based on changes in network trip time and not comparing counted with estimated link's volumes [Friedrich, 2009]. In a study by Qian and Zhang two case studies were analyzed and showed that changing in how to choose connectors has an effect on results of assignment process and the estimated traffic volumes. In this study they have presented an optimization algorithm according to change connector patterns in a way that for certain links, the maximum v/c ratio gets minimum [Qian and Zhang, 2012].

Jeon et al. analyzed the relation between traffic zones number, size of TAZ, and the detail level of network. They have presented a method to minimize errors due to aggregation. To assess the proposed method results some statistical tests are used to estimate reliability. Results for two proposed zoning systems shows acceptable range of error, decrease in required time and cost of model analysis and ease of data gathering [Jeon et al.2010].

It was stated that centroids can be placed in different places for each zone. The more important issue is the way that centroid is connected to main network and with what cost function. As a result, Qian and Jang in 2012 published an article in which they have examined the effects of connector patterns and numbers on the results of static traffic assignment and how to optimize their pattern. For that, in this study three networks are considered as case studies. For each of them according to specific scenarios connectors were considered for each traffic zone and demand was assigned. In this research it is concluded that static traffic assignment results have high sensitivity to changes due to different selection of connectors and results improvement by changing number of connectors are impossible. In many scenarios travel time of network and average volume are estimated less than real values. In case of not having enough information about origin and destination points of travels and their routes, the random connections could result to an improper estimated link volumes which can be more or less than real values.

A few numbers of researches has investigated the number of connector's effect on traffic assignment results. One of these studies is Mamdoohi et al research at 2010 in Iran. In this research besides showing the effect and importance of the connection pattern, the efforts have been made to estimate the optimum number of connectors. Finding optimum number of connectors is based on a comparison between counted volumes and the assignment results in different connection patterns in Mashhad city as a case study. In this research, network of Mashhad city with 141 traffic zones, 3830 links and 1341 nodes is considered. To connect centroids to main network, 6 different patterns are considered. These patterns range from one connector for each zone to 6 connectors. To investigate the effect of different connector patterns, the assignment results are compared with observed volumes of 87 selected links. After assigning demand to network, the equilibrium volumes in links and observed volumes are compared. The results of this comparison are presented in form of some statistical descriptive respecting the error in different scenario patterns. They have concluded that the optimum number of connectors is one for each zone which would lead to lower mean and standard deviation of volume error. In order to investigate deeper, the observation-estimation plots are used. The coefficient of determination in this plot alters from 0.54 for one connector to 0.39 for 6 connectors. Then the previous conclusion is proved because the coefficient of determination is more in one connector scenario.

In a study done by Bashirinia and Mamdoohi in 2017, in order to analyze quantitatively and implement different scenarios of connection pattern and number of connectors from centroid to main nodes of network, the Qazvin city in Iran was used as a case study. In this research 6 different connection patterns were used and each one's assignment results were compared with the base scenario results (Master plan). In order to do the comparison, the measures like distribution function of volumes and speeds in links, distribution function of connectors volume, average links volume and speed, total travel distance, total travel time, total emitted pollution and total consumed fuel are used. The connection scenarios were made ranging from one connector for each traffic zone to all possible connectors. The results show that changing pattern and number of connectors would result up to 10% change in average volumes and up to 20% decrease in total traveled distance.

In Study of Bashirinia et al.the main objective was to quantitatively analyze the effect of connector patterns on priority of different network development projects based on static traffic assignment results. Using user equilibrium and BPR functions, different scenarios including: 1-The master plan's connector pattern (base scenario), 2-Increasing one connector to the base scenario, 3-Just one connection to nearest node, 4-Just one connection to farthest node, and 5-Connection to all possible nodes, was investigated. To implement the concepts, Qazvin city with 113 TAZ and 400 thousands residents was used as case study. In order to compare the scenarios, multi criteria analysis (concordance analysis) was implemented with measures like total travel distance, total travel time, total emitted pollution and total consumed fuel in different weighting systems. The Traffic assignment for each four development projects respecting each five connection patterns scenarios was done. The relative improvement in each measure in order to prioritize the development projects in each connection pattern was calculated. The priority of each development projects was defined using concordance analysis. After doing so, the fourth development project in three different connection patterns (base, patterns 2 & 5) is the first priority for network development. The second development projects in two connection patterns (patterns 3 & 4) is the best network development solution. This results show that changing traffic assignment results with changing the connection patterns are so effective on project selection process in a network development plan [Bashirinia et al.2018].

Jafari et al. in their research, focused in proposing two approach to determine appropriate connector pattern for dynamic traffic assignment applications. The first approach radially distributes the connectors to the nearest nodes and is intended to exemplify some limitations of the most common techniques in practice. In this approach, a circle around the geometric center of TAZ with appropriate radius (according to the zone characteristics and network details) are divided to N sectors (on basis of interested connector's number). Then, the nearest node in each sector is connected to centroid. The second approach is the extension of the first approach. This approach involves dividing the centroid and subsequent demand into two parts, distributing the demand across one sub centroid linked to nearby nodes and one linked to the periphery, and thus effectively establishing a bi-level distribution. To compare the results of traffic assignment on basis of these approaches to the base scenario with conventional connecting approach, a part of city in Texas, USA, with 158 TAZ was considered as case study. The results of comparison show that the difference between observed and estimated links volume using the bi-level approach, is reduced by 10% while the first approach does not improve the estimation results [Jafari et al.2015].

Because the assignment model results are used to compare the various network development options, some experts believe that the change of connector patterns affects these results to a limited extent, and therefore the order of priority preference remains constant. A review of various research and literature on this subject shows that the effect of connection pattern change on network development projects prioritization would be significant. In this paper, it has been tried to provide a suitable approach and model to increase the accuracy of the assignment process. In the proposed alternative approach, there is no need to change the structure of TAZ, their centroids and connectors, and the only intra-zonal travel time is modeled as a random variable (instead of the connectors), and used in the assignment model.

3. Methodology

The main goal of this study is how to consider the travel time within traffic zones instead of simple connectors. This part of travel time is the duration of the trip starting from the real origin to the main network (from the main network to the real destination of trip). In classical traffic assignment approaches, a point within the zone (usually its geometric center) is known as the representation of the entire production and attraction points of that zone and its connection to the main network is possible on basis of various patterns. As stated above, how to connect the centroids to the main network, the number of connectors, how to calculate the travel time in those links, and the dependence of the travel time of this links to their passing volume are the issues that change the assignment results. Hence, in this study, the random variables of travel time within TAZ will be introduced instead of using centroids and connectors as an alternative approach.

The proposed algorithm in the present study does not need to change the structure of TAZ and dimensions of the travel demand matrix. Thus, in order to eliminate the error arising from the assumption of the existence of a center for each TAZ and its connection with virtual links (randomly or by expert judgment), each trip from its original destination to its main destination is divided into three main parts:

1- Internal access trip in the origin zone to the main road

2- Trip through main roads between the origin and the destination zone

3- Internal access trip in the destination zone until the final destination

The main focus of this study is on access part of travel within the origin and destination zones (part 1 and 3), so that they can be considered more carefully than the conventional procedure (using connectors) in the assignment model. For the internal network of each zone, a number of nodes are considered as connection nodes, and the travel between the zones is actually considered between the two connecting nodes of those zones. Using this decomposition, the total travel time from the origin zone (r) to the destination zone (s) can be rewritten through the i-th connection node at the origin to the j-th connection node at the destination $\left(\mathrm{T}_{ij}^{rs}\right)$.

$$\mathrm{T}_{ij}^{rs} = t_{r_i} + t_{r_i s_j} + t_{s_j} \tag{1}$$

Where t_{r_i} is a random variable to explain the access time from the real origin to the i-th connection node in the zone r (similarly t_{s_j} is a random variable to explain the access time from the j-th connection node in the zone s to the final destination) and $t_{r_i s_j}$ is the minimum travel time between the i and j connection nodes in the main network (which is calculated using shortest path determination methods and cost functions of the network links).

In this research, the “random variable” intra-zonal travel times are represented as alternatives for connectors. By considering this variable and using discrete choice models, the share of possible routes for each OD demand can be determined. Although to reach this goal, a list of all possible routes (between each OD pairs) is needed. Determining all possible routes between all OD pairs is the main problem of path-based assignment methods. As a solution to this problem, in this study, without generating all routes between OD pairs, few possible nodes from the main network in each TAZ are selected and the shortest path problem between all this candidate nodes in different zones will be solved.

In classic traffic assignment methods, to model a trip between a specific OD, two virtual links (connectors) as intra-zonal trips and few main links as inter-zonal trips are considered (Figure 1a). In the proposed alternative approach of this research, by eliminating connectors, the process of solving the assignment problem is changed. By this elimination, centroids are changed to few candidate nodes which could be connected to main network. In the proposed approach if *n* nodes in origin zone and *m* nodes in destination zone are considered, the possible ways to have a trip between this OD pair would be $m \times n$. In the assignment process of the alternative approach, among each pair of candidate nodes, the shortest path is represented. Therefore, between each OD pair, $m \times n$ shortest path will be determined (Figure 1b).

A remained tip in this step, is to determine the volume of each shortest path. According to this study suggestion, by using the concept of discrete choice models and intra-zonal travel time random variable distribution, the share of each $m \times n$ shortest path of the demand from origin to destination will be calculated.

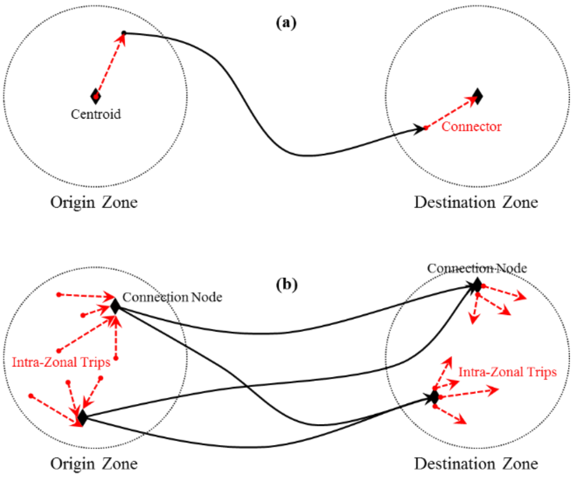

Figure 1. Trip decomposition: (a) Conventional pattern, (b) Proposed alternative approach

Based on discrete choice models theory for determining the share of each alternative, a utility function is needed. Utility function in the choice theory is consisted of a known and certain part (V_i) while it has an unknown and uncertain component (ε_i). The known part of utility function in our problem (route choice in traffic assignment) is equal to the shortest travel time of selected paths between the pairs of candidate nodes and the unknown part is consisted of intra-zonal travel time random variable. Thus, the share of each alternative could be calculated by using the Equation (2). This equation is rewritten using intra-zonal and inter-zonal travel time (Equation (3)).

$$Pr_i = Pr(U_i > U_j) = Pr(V_i - V_j > \varepsilon_i - \varepsilon_j) \quad \forall j \neq i \qquad (2)$$

$$\begin{aligned} Pr_{r_i s_j} = Pr\left(U_{r_i s_j} > U_{r_p s_q}\right) &= Pr(\mathrm{T}_{ij}^{rs} < \mathrm{T}_{pq}^{rs}) \\ &= Pr\left(t_{r_i s_j} - t_{r_p s_q} < t_{r_p} + t_{s_q} - t_{r_i} - t_{s_j}\right) \end{aligned} \qquad (3)$$

$$\forall i \neq p\,, \forall j \neq q$$

Where:

$Pr_{r_i s_j}$: The share of shortest path between the i-th connection node at the origin (r) to the j-th connection node at the destination (s) of total demand from r to s

$U_{r_i s_j}$: The utility function of shortest path between the i-th connection node at the origin (r) to the j-th connection node at the destination (s)

By knowing the distribution of intra-zonal travel time as a random variable and its parameters (such as mean and variance) and using discrete choice models, the probability of choosing each shortest path and its share of OD demand can be calculated.

Finally, the alternative approach and its assignment process would be expressed as below algorithm (Figure 2).

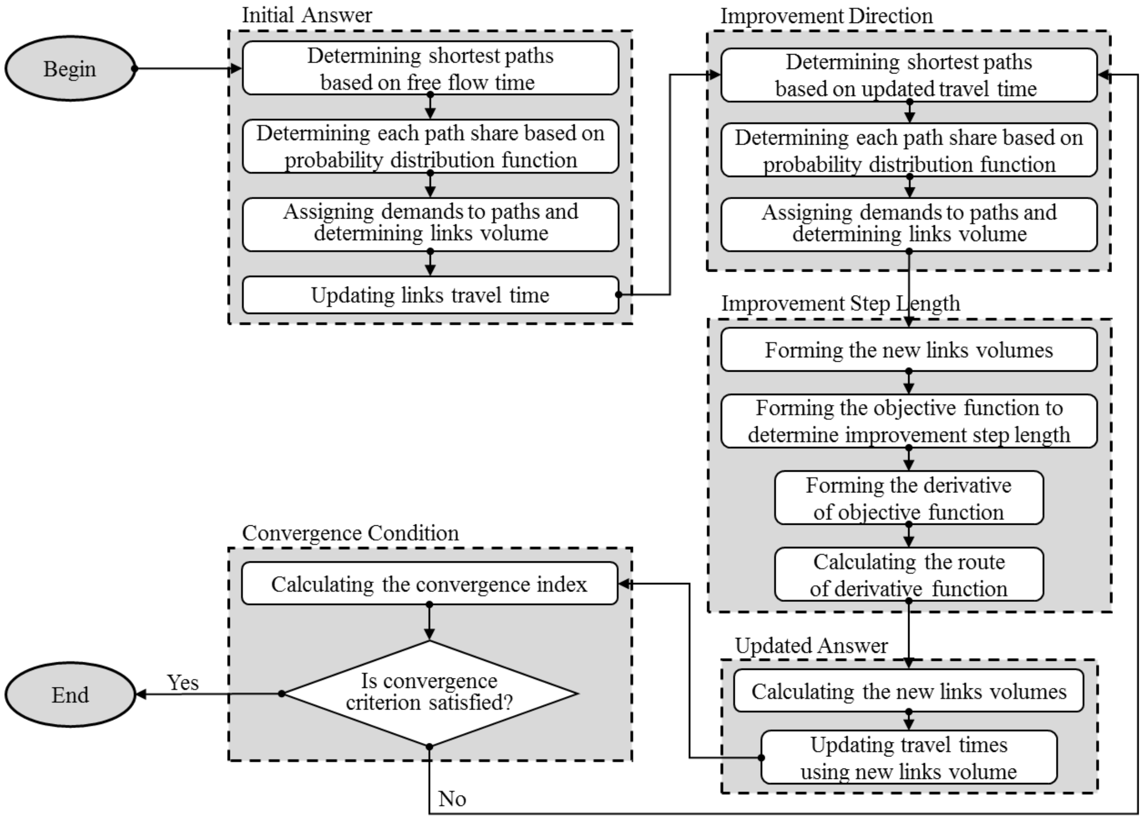

Figure 2. Proposed traffic assignment algorithm

1: Determination of initial answer

1-Determining the shortest path between all pairs of nominated nodes based on free flow travel time (T_0)

2-Determining each shortest path share of total OD demand based on travel time and probability distribution function (P_0)

3-Assigning the determined demands to paths and determining network links volume (X_0)

4-Updating links travel time by using volume-delay function and present volume data (T_1)

2: Determination of improvement direction

1-Determining the shortest path between all candidates nodes based on updated travel time

2-Determining the shortest paths share of total demand based on updated travel time and probability distribution function

3-Assigning the determined demand to paths and determining network links volume (Y)

3: Determination of improvement step length

1-Forming the new links volumes

$$X_{new} = X_{previous} + \alpha\left(Y - X_{previous}\right) \tag{4}$$

2-Forming the objective function to determine improvement step length

$$Z(\alpha) = \sum_i \int_0^{x_{i,new}} T_i(w_i)dw \tag{5}$$

3-Forming the derivative of above objective function

4-Calculating the route of mentioned derivative function (α)

4: Determining the updated answer

1-Calculating the updated links volumes

2-Updating links travel time using volume-delay function and new volume data

5: Controlling the convergence condition

1-Calculating the convergence index (difference of links volume or travel time)

2-Comparing calculated convergence index to desired value

3-In case of reaching stop condition, end of algorithm and reporting the result

4-Return to second step (Determination of answer improvement direction)

4. Characteristics of Case Study

In this study, the transportation network of a real-size city (Qazvin city in Iran) with area of 4.6 km^2 and approximately 400 thousand residents were used as the case study. The characteristics of mentioned network and its travel demand are listed in Table 1.

To produce the results of traffic assignment on bases of conventional centroid approach and proposed alternative approaches, in this research, Frank-Wolfe method is used in UE traffic assignment model. In this model the links delay functions are based on BPR which their parameters for the case study network, are shown in Table 2.

The results of traffic assignment model using centroids and connectors show that the total traveled distance is 417550 veh-km, the total time spent is 18070 veh-hr, the total fuel consumption is 64900 lit, and the total emitted pollutant is 30.9 ton.

Table 1. Characteristics of Qazvin transportation

Item	Amount
Number of TAZ	113
Length of Network (km)	260
Number of Links	2300
Number of Nodes	1200
Number of Connectors	181
Total Peak Hour Travel Demand (pc)	69000
Average Peak Hour Travel Demand between OD Pairs (pc)	5.4
Maximum Peak Hour Travel Demand between OD Pairs (pc)	224
Average Daily Trip Rate (trip per capita)	1.6
Peak Hour Share of Daily Travel Demand (%)	15

According to the distribution of links volume (Table 3) the major part of network links (64%) has a volume less than 2000 pc/hr and the volume of 67% of total network length is in this range.

Table 3. Distribution of links volume in traffic assignment model based on conventional pattern

Link Volume (pc/hr)	Share of Network Links (%)	Share of Network Length (%)
Less than 500	13	17
500 to 1000	18	19
1000 to 1500	17	17
1500 to 2000	16	14
2000 to 2500	11	10
2500 to 3000	9	10
3000 to 3500	6	6
3500 to 4000	4	4
4000 to 4500	3	1
4500 to 5000	1	1
More than 5000	2	1

Table 2. Characteristics of BPR Links Delay Functions Parameters

Link Type	Total Length (km)	Share of Total Network Length (%)	Free Flow Speed (Km/hr)	Nominal Capacity (pc/m)	α	β
Urban Freeway	8	3	70	400	0.330	4.213
Major Arterial	49	19	50	370	0.521	3.468
Minor Arterial	57	22	40	285	0.426	4.506
Collector	134	51	35	265	0.703	3.059
Ramp/Loop	12	5	30	200	0.150	5.000

5. Results of the Proposed Approach

To implement the proposed approach on case study network, for each TAZ a set of candidate connection nodes are selected. The number of candidate connection nodes for TAZs are different respecting the TAZ areas. The central TAZ, in Qazvin CBD, which are usually smaller has 4 candidate connection nodes. Around the CBD, which TAZs are more bigger but still have high population density, number of candidate nodes become higher than CBD. By moving outside the city TAZs may become bigger without enough developed network, therefore the number of candidate nodes is less than previous zones. The average and standard deviation of number of candidate nodes for TAZ of Qazvin city are 4 and 0.7, respectively (Table 4).

Table 4. Distribution of number of candidate nodes in TAZs

Number of Candidate Nodes	Share of Total TAZs (%)
3	17
4	67
5	10
6	6

After candidate nodes determination with assuming no complimentary information about intra-zonal travel time, the Logit discrete choice model is used to determine the share of each path. The Logit probability distribution parameters are assumed standard as usual.

By implementing proposed alternative approach with Logit model in traffic assignment procedure, the total performance indexes of network (e.g. VKT, VHT) were decreased by 15%. This situation could be the result of considering the real behavior of intra-zonal trip and relaxing the assumption about the aggregation of origin and destination of trips.

The total network performance indexes, are usually used to assess and compare different network development scenarios. In this study the connector and assignment procedure has been changed and as a result the total network performance indexes are not so useful to compare the new approach with traditional traffic assignment procedures. In contrast, the proposed alternative approach effectiveness would be tested using the accuracy of volume estimation. To do so, 125 links were examined based on their observed volume and estimated using the proposed alternative approach.

The comparison of estimated link volumes using the proposed approach of this study (Figure 3) shows a more accurate estimation of observed volume than conventional connection patterns. The average error in volume estimation using the proposed approach equals to 231 pc/hr (18%) while this index using conventional pattern is 305 pc/hr (23%).

Another way to compare the results is to use error distributions. In order to compare two distributions, the Kolmogorov-Smirnov test is used. This test compares two distributions without knowing type of them and it shows if two distributions are the same or not. In this test the supremum value of differences between two distributions is compared to the critical value. The zero hypothesis is the similarity of distributions. If the calculated statistics is greater than the critical value, the zero hypothesis will be rejected.

Assuming 5% confidence level and 125 observations of links volumes, would result the critical index value of 17.2%. Comparing the cumulative distribution of estimated volumes of using proposed alternative approach with the conventional pattern results (Figure 4) lead to Kolmogorov-Smirnov statistic test value equals to 18.1% which is greater than the critical value. So the similarity of these two distributions is rejected at confidence level of 5%. Therefore, by doing a minor correction in network structure and traffic assignment algorithm, more accurate and realistic results could be achieved.

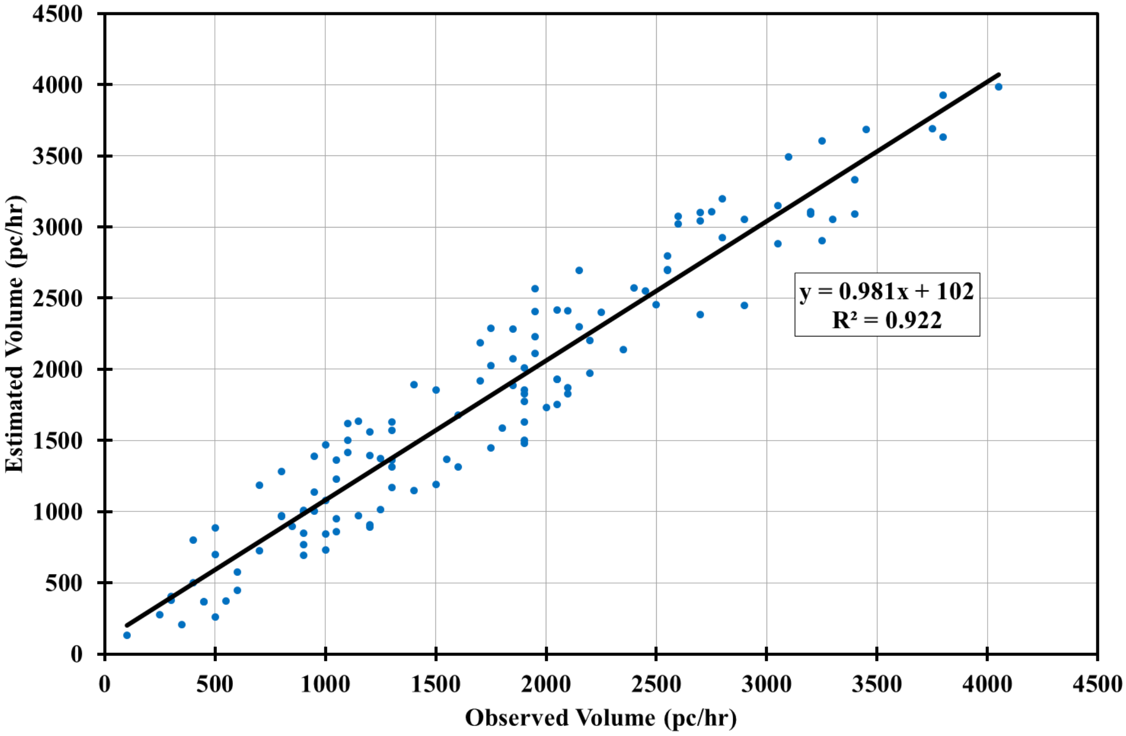

Figure 3. Comparing observed volumes with estimated volumes using Logit model

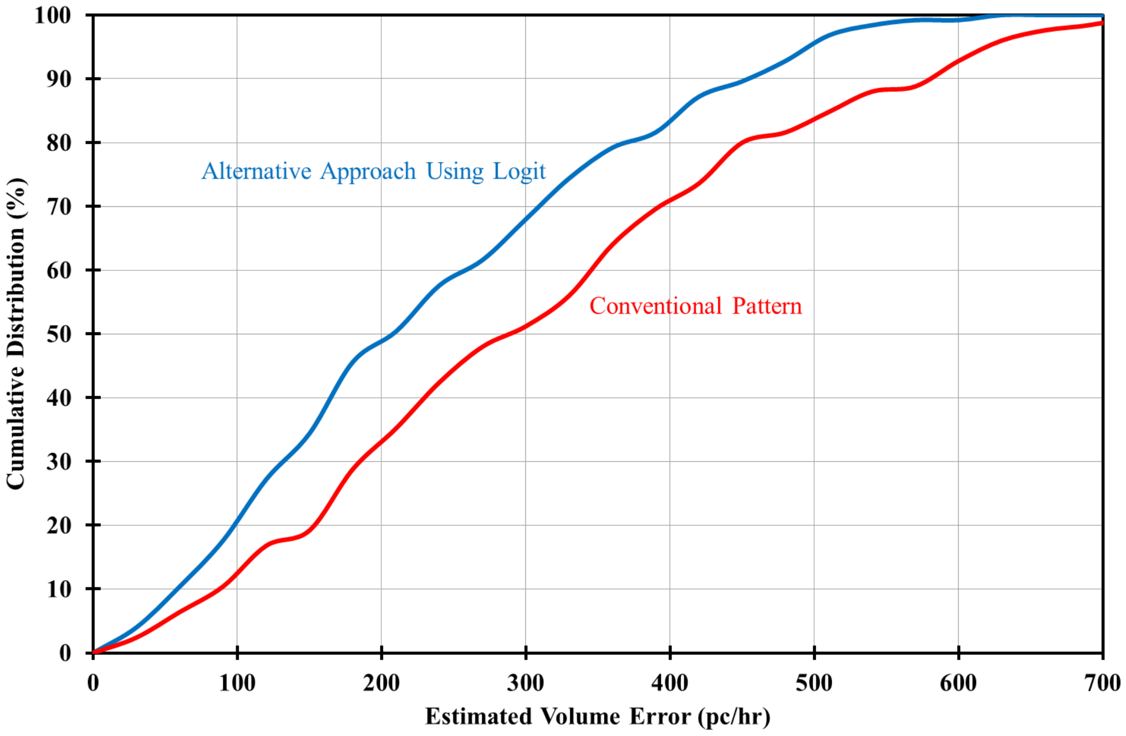

Figure 4. Cumulative distribution of estimated volumes error using Logit model

In each iteration of the modified assignment algorithm using the proposed alternative approach, share of competitive routes for the trip from each origin to the destination must be computed using the Logit choice model. This procedure will take more time compared with assigning total demand to the shortest path for each iteration in traditional approach. In the case of Qazvin, the traffic assignment time has increased from 3 seconds (conventional connection pattern) to 28 seconds. It seems that in spite of a tenfold increase of the model analysis duration, due to the improvement in estimation of links volume (reduction of the root mean square error by 20% and the results of the K-S test), using the proposed approach is affordable.

Another famous discrete choice model is Probit. So, in addition to Logit model, proposed alternative approach is re-implemented using Probit choice model, with the assumption of normal distribution for the intra-zonal travel time. The results of proposed traffic assignment algorithm using the Probit model show that total network performance indexes are about 16% lower than the conventional pattern and 1.2% lower than the Logit route choice model.

In addition to the total network indexes, the graph of observed and estimated volume in selected links has been studied (Figure 5). Regression analysis and average error of estimated volume (230 pc/hr (17%)) show that there are no significant differences in results of assignment using proposed alternative approach with Probit and Logit models.

The comparison of the probability error of estimating traffic volume distribution (Figure 6) shows that the maximum difference between the distribution of error of the conventional pattern and the proposed algorithm using the Probit model is 18.4%. The computed K-S statistic is higher than the critical value (17.2%), with 5% confidence, so the similarity of the two distributions could be rejected. Of course, the results of using the Probit model for this test are not significantly different from the Logit model (18.1%) and slightly better.

In each iteration of the modified assignment algorithm, using the proposed alternative approach, share of competitive routes from each origin to each destination should be computed using the Probit choice model. Since the Probit model is not a closed form model, share of competitive routes should be calculated using simulation and random drawing (100 points for each OD in each iteration). This procedure will take more time compared with assigning total demand to the shortest path for each iteration in traditional approach or using Logit model. In the case of Qazvin, the traffic assignment time from 3 seconds for the conventional connection pattern increased by 28 seconds for the proposed approach using a Logit model and by 12 minutes for the Probit model.

Based on the convergence criteria, in the implementation of the modified algorithm using the Probit model for Qazvin, the equilibrium condition has been reached after 18 iterations. Regarding the number of iterations of proposed alternative approach using Logit model (15 iterations), using the Probit model, makes achieving to equilibrium relatively harder. This increase can be due to the lack of mathematical closed-form and less precision with the use of simulation to calculate the probabilities.

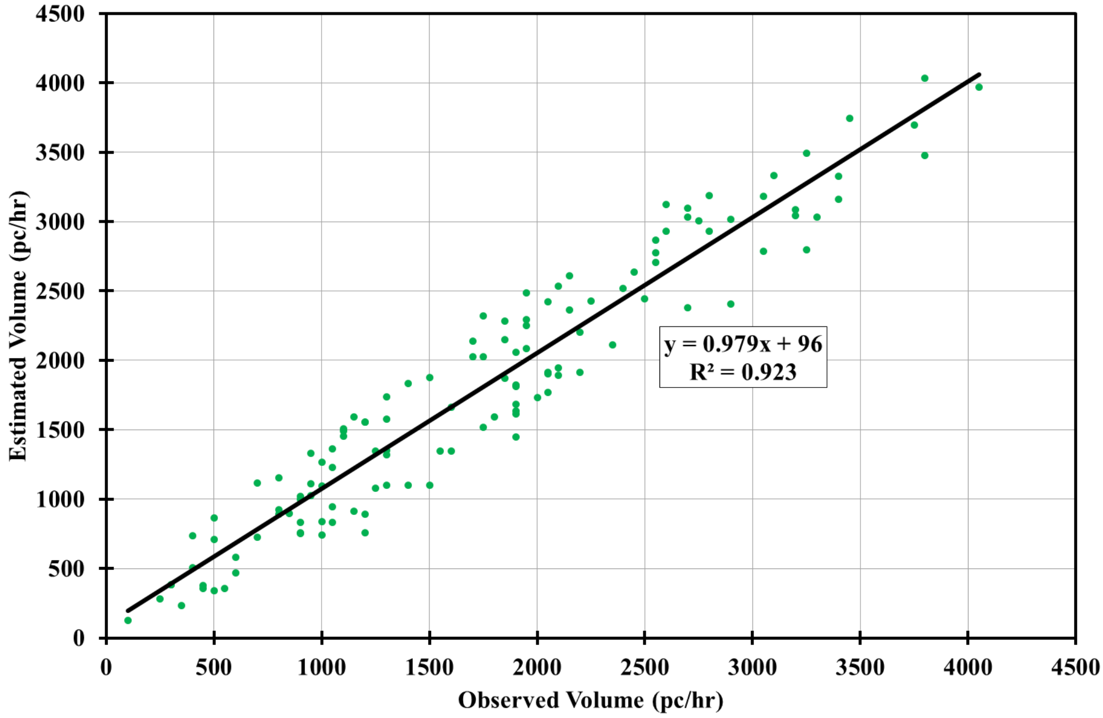

Figure 5. Comparing observed volumes with estimated volumes using Probit model

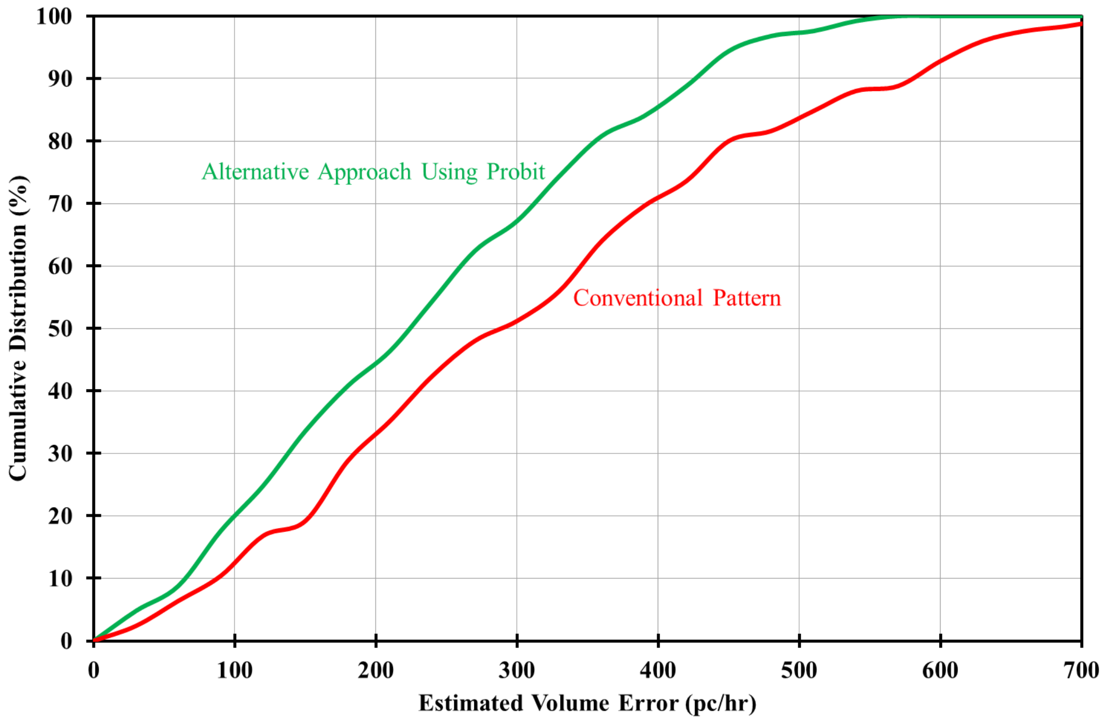

Figure 6. Cumulative distribution of estimated volumes error using Probit model

Table 5. Traffic assignment results of the proposed alternative and conventional approaches

Criteria	Conventional Connection Approach	Proposed Alternative Approach Using Logit	Proposed Alternative Approach Using Probit
VKT	417,550	351,650	344,813
VHT	17,794	15,021	14,872
Average Volume Estimation Error (%)	23	18	17
Volume Estimation RMSE (%)	30	24	22
Estimated-Observed Goodness of Fit (R^2)	0.873	0.922	0.923
K-S Test Statistics (%)	-	18.1	18.4
Model Solution Time (Sec)	3	28	720
Number of Iterations	18	15	18

It seems that the use of Probit model, in spite of improving links volume estimation, due to significant increase in the method complexity and consequently increase the solution time more than 20 times compared with the Logit model, has not been able to improve the results tangibly and significantly, and therefore its use is not so cost-effective and efficient. The summary of mentioned comparisons is presented in the form of Table 5.

In addition to mentioned statistics in Table 5, the relationship between errors of estimated links volume and links type and links volume are shown in Table 6 and Figure 7, respectively.

Generally, relative errors in estimation of links volume, have an inverse relationship with links volume. According to Figure 7, almost all of the points related to assignment on basis of alternative approaches, are below the point resulting from assignment using conventional pattern. It implies that proposed alternative approaches increase the accuracy of estimation in all ranges of links volume.

As can be seen in Table 6, the average absolute errors in volumes estimation of collector links, are less than arterials and freeways, using all approaches. But, because the average volumes of later highways are much higher, the relative errors in volume estimation of collectors are more significant than the others.

In comparison between conventional and proposed approaches, implementing the proposed approaches, especially the Probit, The reduction varies

Elimination of centroids and connectors and implementation of alternative proposed approaches may cause to reduce estimation errors in all link types. Generally, the link estimation on basis of Probit route choice model, is more precise than Logit one. The reduction in link volume estimation error using Probit model in comparison to conventional approach, varies from 21% for major arterials to 28% for collector links.

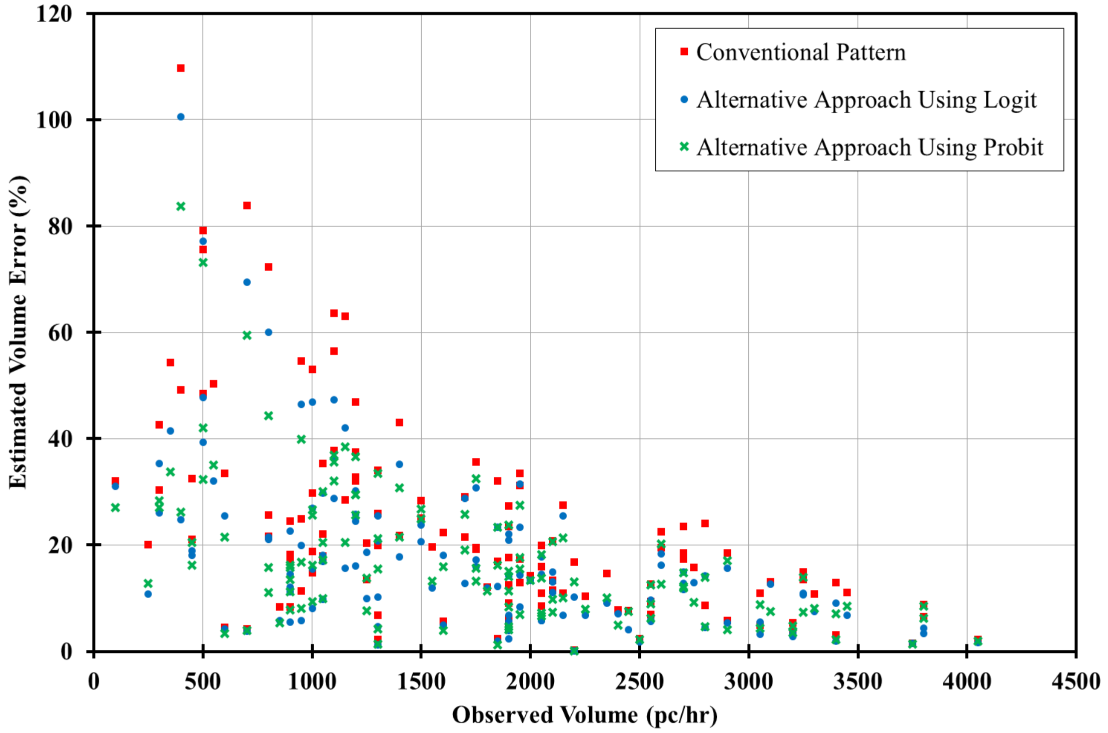

Figure 7. Dispersion of relative errors of estimated links volume in observed volume range

Table 6. Average errors in estimation of volumes for various link type, using different approaches

Link Type	Number	Conventional Pattern		Alternative Approach Using Logit		Alternative Approach Using Probit	
		Error (pc/hr)	Error (%)	Error (pc/hr)	Error (%)	Error (pc/hr)	Error (%)
Urban Freeway	15	274	8	189	6	211	6
Major Arterial	29	337	14	252	10	257	11
Minor Arterial	48	353	25	269	18	277	19
Collector	33	222	36	178	29	153	25

6. Conclusions and Suggestions

The results of previous studies showed that the change in connection patterns can have an effect up to 10% on estimated links volume and up to 20% on total travel time and total traveled distance. Also different connection patterns can make major changes to the prioritization and evaluation of different network development projects. According to the number of possible scenarios for connection patterns in a network and number of parameters, measures and indexes for comparison, creating an optimal connection pattern is very difficult and even impossible. Therefore, in this research, alternative approaches have been studied and this problem has been solved, by considering a random variable for intra-zonal travel time and proposing alternative approach instead of conventional centroids and connectors pattern.

The proposed alternative approach for Qazvin network, with 113 TAZ, assuming two discrete choice models, Logit and Probit, are implemented. The comparison between conventional centroids and connection pattern and proposed alternative approaches results are based on network performance indexes and links volume estimation error. The results of this comparison can be summarized as follows:

1-The proposed alternative approach in comparison with the conventional pattern, changed the total network performance indexes by about 15%.

2-Using proposed alternative approach led to estimate links volume more accurately (20% decrease in average and root mean square error).

3-The Kolmogorov-Smirnov test showed that cumulative distribution of links volume estimation error in alternative approach, is significantly different with conventional approach.

4- The relative errors in links volume estimation, using the proposed approaches for freeways and major arterials are less than minor arterials and collectors.

5- The improvement in estimation of links volume, using proposed approaches, especially Probit model, is more significant for collectors (relative error is reduced by 28% in comparison with conventional assignment approach)

6-Using the Probit model in comparison with the Logit model, due to the assumption of the normal distribution of intra-zonal travel time, slightly increased the accuracy of the results (Improvement of volume estimation error indexes was about 5%).

7-Due to more computational complexity in the proposed alternative approach in comparison with conventional approach, the time to solve the traffic assignment model has become much larger (Increase from 3 seconds to 28 seconds for the Logit model and 12 minutes for the Probit model).

In the present study, an approach and algorithm for UE traffic assignment as an alternative for the using of centroids and connectors was proposed and compared analytically and numerically with the conventional approaches for a real-size city with 113 TAZ. Investigating other traffic assignment methods, using the proposed alternative approach idea for transit assignment methods, using alternative discrete choice models, considering other criteria and indexes for comparison and studying larger networks as case studies, can be suggested topics in future researches.

7. References

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