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Research Article

A Simulation-Based Accessibility Modeling Approach to Evaluate Performance of Transportation Networks by using Directness Concept and GIS

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Abstract

Ranging from simple to sophisticated, numerous types of accessibility measures are found in the accessibility modeling literature which helps to understand accessibility of people, place and transportation networks. Transportation network directness (reciprocal is "circuity"), which is defined as the ratio of the shortest Euclidean distance over network distance between demand (origin) and destination (supply) points, could be considered as an important type of measure for understanding accessibility for a variety of context.

Keywords: *GIS, accessibility modeling, simulation, urban planning, transportation network directness, circuity, test of transportation network performance, Euclidian distance, bird flight distance, network distance*

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Although there are several research and literature on transportation network directness and accessibility modeling, the research that integrates transportation network directness concept into accessibility modeling process in such a way to provide understanding of the overall accessibility performance of the transportation networks without losing the local interactions is quite limited.

Based on this idea, the basic aim of this research is to propose a new transportation network directness-based accessibility modeling methodology that could be used to test both the local and the overall accessibility performance of transportation networks in a simple and comparable manner by using GIS. By considering regularly produced virtual origins and destinations on the transportation network in a "simulation" manner, the proposed methodology could produce "travel time/distance" based accessibility measures that could operate without a need for real time supply/demand or origin/destination data.

The advantage of using a virtual regular data set instead of real time data is that; it is more simple, easy to operate and most importantly, more realistic to understand performance of transportation networks as most of the possible origin/destination scenarios could be represented in the proposed model. The outputs of the model could be widely used by the decision-makers who are supposed to deal with accessibility, location/allocation, and service/catchment area related issues by several aims such as; to test the overall/partial performance of the transportation networks, to understand the weakly connected parts of the transportation network and/or to compare the accessibility performance of different networks with each other.

The proposed methodology is applied in 3 cities with different types of transportation network which are Paris, FRANCE (radial network); San Francisco, USA (grid network) and Ankara, TURKEY (mixed network) in order to able to demonstrate the performance and efficiency of the proposed model. The main focus of the case study is not to evaluate specific accessibility conditions or transportation network performance in a detailed manner but to provide a methodological discussion about the proposed directness based accessibility modeling process.

INTRODUCTION

Understanding accessibility of people, place and transportation networks is a challenging research area. Ranging from simple to sophisticated, numerous types of accessibility measures are found in the accessibility modeling related literature such as;

a) Travel time/distance based measures or service/catchment areas (consider travel time or distance to nearest supply/demand calculated by using Euclidian/Network-based costs) (see AultmanHall, Roorda, & Baetz, 1997; Liu & Zhu, 2004; Tsou, Hung, & Chang, 2005; Bagheri, Benwell, & Holt, 2006; Vandenbulcke, Steenberghen, & Thomas, 2009; Chang & Liao, 2011; Ertugay &

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Duzgun, 2011; Boscoe, Henry, & Zdeb, 2012; Monzon, Ortega, & Lopez, 2013; Niedzielski & Boschmann, 2014; Teunissen, Sarmiento, Zuidgeest, & Brussel, 2015; Yamu & Frankhauser, 2015; Ford, Barr, Dawson, & James, 2015; Cetin, 2015; Thevenin, Mimeur, Schwartz, & Sapet, 2016; Saghapour, Moridpour, & Thompson, 2017)

b) Cumulative opportunity measures (consider the total amount of demand/supply inside the catchment area of a location) (see Liu & Zhu, 2004; Curl, Nelson, & Anable, 2015; Bok & Kwon, 2016; Macedo & Haddad, 2016; Wei, 2017; T. E. Laatikainen, Piiroinen, Lehtinen, & Kytta, 2017; Kalantari, Khoshkar, Falk, Cvetkovic, & Mortberg, 2017)

c) Population to provider ratio measures (supply to demand ratio calculated inside a catchment area) (see Luo, 2004; Scott, Larson, Jefferies, & Veenendaal, 2006)

d) Kernel density measures (use the Gaussian kernel approach to calculate the density value of each demand/supply) (see Guagliardo, 2004; Yang, Robert, & Ross, 2006; Gibin, Longley, & Atkinson 2007; Delso, Martin, Ortega, & Otero, 2017)

e) Gravity-based measures (a combined indicator of accessibility and availability by considering the attractiveness of supply/demand) (see Kwan, 1998; Guagliardo, 2004; D. B. Hess, 2005; Moya-Gomez & Garcia-Palomares, 2015)

f) Two-step floating catchment area measures/2SFCA measures (repeat the process of catchment area calculation for both supply and demand points considering the overlay zones etc.) (see Wei Luo, 2003; W. Luo & Wang, 2003; Luo, 2004; McGrail & Humphreys, 2009; J. Luo, 2014; Dony, Delmelle, & Delmelle, 2015; Xu, Ding, Zhou, & Li, 2015; Luo et al., 2018)

(For a detailed review about accessibility measures, see W. Luo & Wang, 2003; Guagliardo, 2004; Bagheri, Benwell, & Holt, 2006; McGrail & Humphreys, 2009)

Whether simple or sophisticated, accessibility measures are widely used by geographers, economists, and urban and transportation planners to “identify regions that have inadequate or excessive service”, “to select appropriate sites for new or re-located services” or “to evaluate the performance of the transportation networks”.

Transportation network directness (reciprocal is “circuity”), which is defined as the ratio of the shortest Euclidean distance over shortest network distance between demand (origin) and destination (supply) points, could be considered as an important type of travel time / distance based measure for understanding accessibility (Levinson and El-Geneidy, 2009; Barthelemy, 2011; Huang, & Levinson, 2015).

The directness ratio (DR) scores between origins and destinations could be calculated by using the following formula (Equation 1) (Barthelemy, 2011).

$$DR_{i\,j} = \frac{D_{ij}^{e}}{D_{ij}^{n}} \qquad \text{Equation 1}$$

According to equation 1; $DR\,(i,j)$ represents Directness Ratio between Origin(i) and Destination(j); D_{ij}^{e} represents Eucledian based distance between Origin(i) and Destination(j) and D_{ij}^{n} represents network based distance between Origin(i) and Destination(j).

The reciprocal of the DR (i,j) (directness ratio) is the CR (i,j) (circuity ratio) which can be defined as the as the ratio of the shortest network distance over the Euclidean distance between (origin (i) and destination (j) points (Equation 2) (Huang, & Levinson, 2015).

$$CR_{i\,j} = \frac{D_{ij}^{n}}{D_{ij}^{e}} \qquad \text{Equation 2}$$

There are several research and literature considering transportation network directness / circuity for a wide variety of context. For example; Ballou, Rahardja, and Sakai (2002) explained that road distances estimated from distance functions must be corrected by a circuity index considering road network density, connectivity, and travel obstacles such as mountains, lakes etc, in order to approximate the actual travel distances which could be useful in designing logistics networks, routing vehicles, and planning geography based applications. Dill (2003) applied “Pedestrian Route Directness” in Portland, Oregon region to understand the connectivity / accessibility / attractiveness level of urban regions for cycling and walking. The research also summarizes the literature about measures of connectivity, drawn from transportation, urban planning, geography and landscape ecology etc. Levinson and El-Geneidy (2009) used circuity measure for better understanding of the choice of residential location relative to work in a comparable manner. The findings contribute to residence choice and location theory and help to understand how workers tend to locate with respect to network conditions. Barthelemy (2011) reviewed the spatial properties and constraints of the many important measures and models about spatial networks and mentioned about the evaluation of the

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directness and circuity indexes. Bejleri, Steiner, Fischman, and Schmucker (2011) presented a GIS based methodology that analyzes children travel to school as a function of network distance considering the role of constraints/barriers and facilitators to understand accessibility/walkability between origin and destination. Papinski and Scott (2011) used GPS based inputs and generated some variables as outputs describing route characteristics such as distance, travel time, speed statistics, number of intersections, number of turns, number of stop signs/stop lights, and a measure of route circuity, etc. by using GIS. Lin et al. (2014) used "walking or driving route directness" to understand accessibility around train stations for the elderly population. Y. J. Lee, Choi, Yu, and Choi (2015) develop a geographical presentation method to demonstrate which parts of the city need to be improved in terms of directness / circuity of the transit services. Huang and Levinson (2015) analyze the circuity of transit networks to understand the accessibility performance of urban transit systems in the metropolitan areas. Giacomin and Levinson (2015) also measure the circuity of the fifty-one most populated Metropolitan Statistical Areas (MSAs) in the United States and tried to understand trends in circuities. (see also other examples; (P. M. Hess, 1997); (Randall & Baetz, 2001); (K. Lee & Ryu, 2004); (Gutierrez & Garcia-Palomares, 2008); (Y. Lee, Washington, & Frank, 2009); (Sparks, Bania, & Leete, 2011); (Bejleri et al., 2011); (Levinson, 2012); (Salonen & Toivonen, 2013); (Vadali & Chandra, 2014); (Balijepalli & Oppong, 2014); (T. Laatikainen, Tenkanen, Kytta, & Toivonen, 2015); (Giacomin & Levinson, 2015); (Cui et al., 2016)).

Although there are several research and literature that use transportation network directness / circuity measure to understand accessibility level of people, place or transportation networks in a "partial" approach, there has been limited research that integrates transportation network directness / circuity concept into accessibility modeling process in such a way that consider most of the possible origin destination combinations in the transportation network in a simulation manner and provide understanding of the "overall" accessibility performance of the transportation networks without losing the local interactions.

Based on this idea, the basic aim of this research is to propose a new directness-based accessibility modeling methodology in a simulation logic, in such a way that consider most of the possible origin destination combinations in the network by using the regularly produced virtual origins and destinations on the transportation network and provide understanding of the “overall” accessibility performance of the transportation networks without losing the “partial” interactions.

The basic advantage of the proposed directness-based accessibility modeling methodology is that; the proposed methodology could produce directness-based accessibility measures in a simple, comparable and easy to operate manner and most importantly, it is more realistic to understand overall and/or partial performance of transportation networks as most of the possible origin/destination scenarios could be represented in the model without a need for additional supply/demand or origin/destination data.

The outputs of the model could be widely used by the decision-makers who are supposed to deal with accessibility, location/allocation, and service/catchment area related issues by several aims such as; to test the overall/partial performance of the transportation networks, to understand the weakly connected parts of the transportation network and/or to compare the accessibility performance of different networks with each other.

The proposed methodology is applied in 3 cities with different types of transportation network which are Paris, FRANCE (radial network); San Francisco, USA (grid network); and Ankara, TURKEY (mixed network) in order to able to demonstrate the performance and efficiency of the proposed model and to provide a comparison in terms of accessibility performance of different types of transportation networks.

THE METHODOLOGY

The general framework of the proposed methodology is given below (Figure 1).

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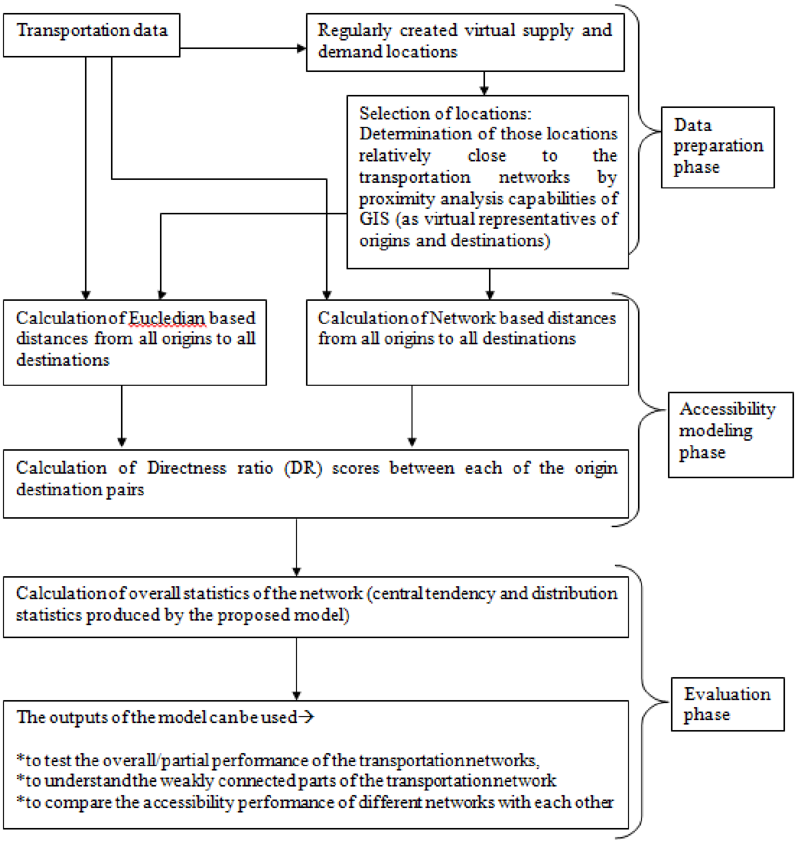

Figure 1. The general framework of the proposed methodology

According to Figure 1, the developed methodology consists of 3 major steps which are 1) data preparation phase 2) accessibility modeling phase 3) evaluation phase.

METHODOLOGY

Data Preparation Phase

This section contains preparation of the data needed for the model's operation. The main input data of the proposed model is the centerlines of a transportation network in GIS environment. Such data could be requested from transportation related departments of local/ central administrations or downloaded from several web based data servers.

By considering the size/boundary of the used transportation network data, the proposed model a) generates regularly created virtual supply and demand locations, b) determines of those close to the transportation networks by proximity analysis capabilities of GIS, c) decides which origin and destination locations will be included in the model in an automated process.

Virtual supply and demand locations are created by fishnet function of ArcGIS software. The function needs a geographic extent to operate and creates rectangular cells of polygon features with centroids according to the parameters of number of rows/columns or cell size width/height (see Figure 2). Created locations are considered as both origin (demand) and destination (supply) locations and used as input datasets for calculation of directness based accessibility scores.

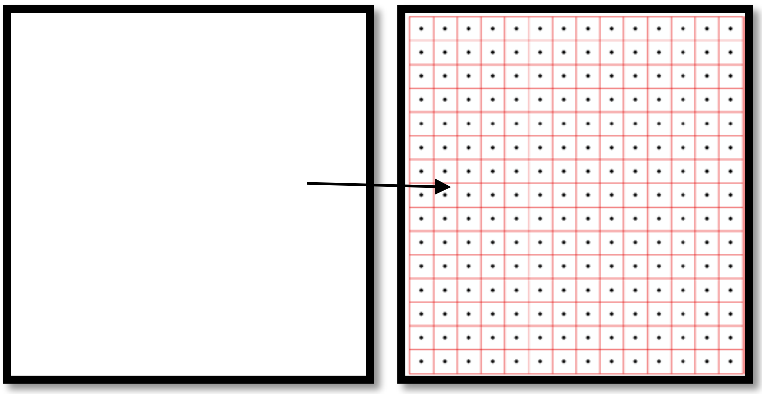

Figure 2. Virtual supply and demand locations are created by fishnet function of ArcGIS software which needs a geographic extent to operate and creates rectangular cells of polygon features with centroids according to the parameters of number of rows/columns or cell size width/height

The model does not use all regularly created origin/destination locations but use ones relatively close to the transportation network. For determination of those virtual locations close to the transportation networks, the proximity analysis and spatial query capabilities of GIS are used. The model first creates buffer polygons considering the scale of the transportation network, and then eliminates the virtual locations that are out of buffer polygon boundaries (see Figure 3).

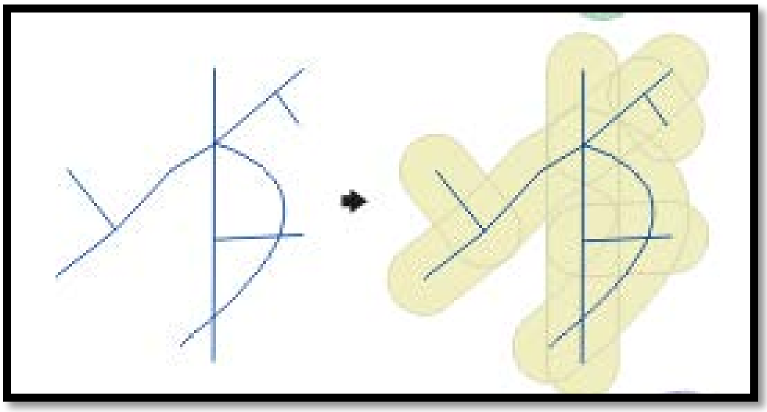

Figure 3. Buffer polygon generation in GIS used for determination of virtual locations close to the transportation networks (Source: ESRI, 2010)

The following part summarizes the data preparation steps related with the case study area. The transportation network datasets used in the case study (Paris, San Francisco and Ankara) is directly downloaded from "OpenStreetMap; https://www.openstreetmap.org", which is one of the free, commonly used web based GIS data server, in July 2016 (see Figure 4). The site covers up to date land use data and transportation network data of most of the cities in the world in GIS environment.

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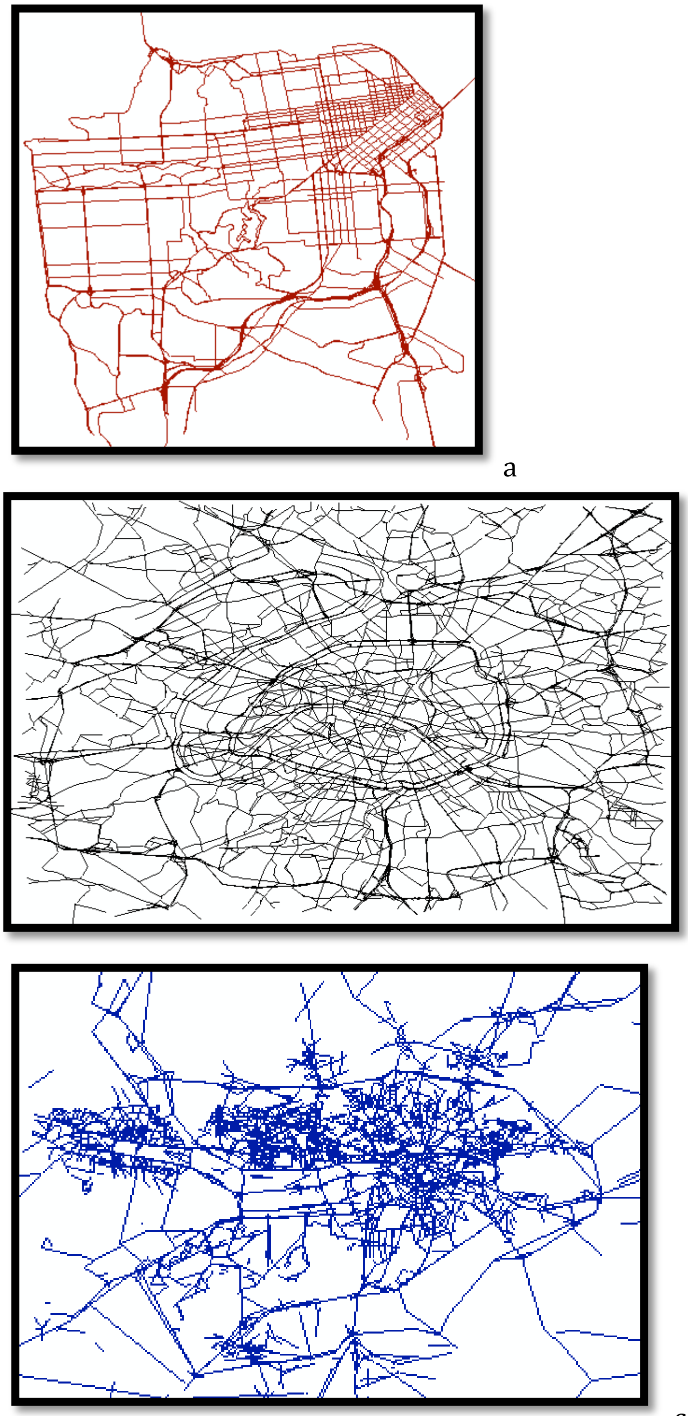

a

b

c

Figure 4. The input transportation network datasets of the model: (a→San Francisco (grid network, b→Paris (radial network), c→Ankara (mixed network)

The reason for using several network datasets is to provide a comparison in terms of accessibility performance of different types of transportation networks in such a way that; San Francisco network carries characteristics of a "grid" based system, Paris network carries characteristics of "radial" or also called "spider web" based system, Ankara network carries characteristics of a mixed system that use partial grid, partial radial and partial organic systems.

In the first step of data preparation phase; by considering the size/boundary of the transportation network data sets, virtual supply and demand locations are created in a regular manner by using regular/random point generation capabilities of GIS (Figure 5).

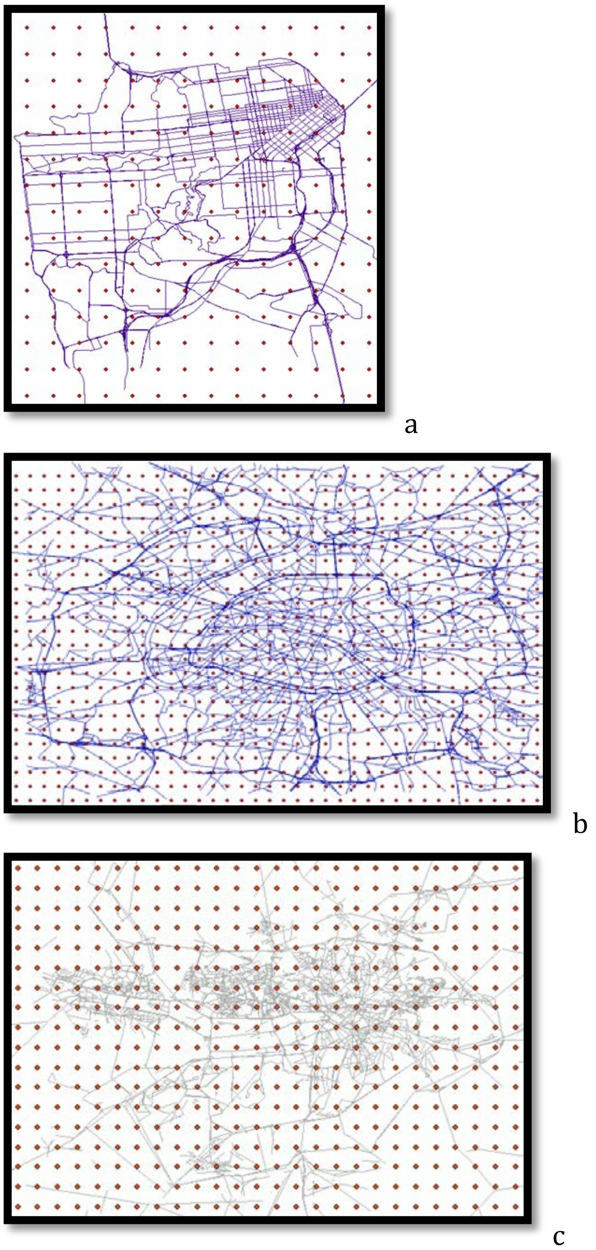

Figure 5. Regularly created virtual supply and demand (origin/ destination) locations considering the size/boundary of the related transportation network data (a→San Francisco (grid network, b→Paris (radial network), c→Ankara (mixed network)

The advantage of using a regularly created virtual origins and destinations to model accessibility is that; it is simple, easy to operate without a need for real time supply/demand or origin/destination data and most importantly, more realistic to understand overall or partial performance of transportation networks as most of the possible origin/destination scenarios could be represented in the proposed model.

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In the second step; regularly created locations are subject to a selection process according to their proximity to the transportation networks by using spatial query capabilities of GIS. This step helps to eliminate the origin destination locations which are definitely far from transportation networks (Figure 6). The highlighted (red) locations in Figure 6 show the ones which are relatively close to the transportation networks. The threshold for the buffer operation is considered as 50 meters for each of the transportation network. However the buffer threshold could be increased or decreased by the decision makers according to the aim, detail need and transportation network characteristics of the research.

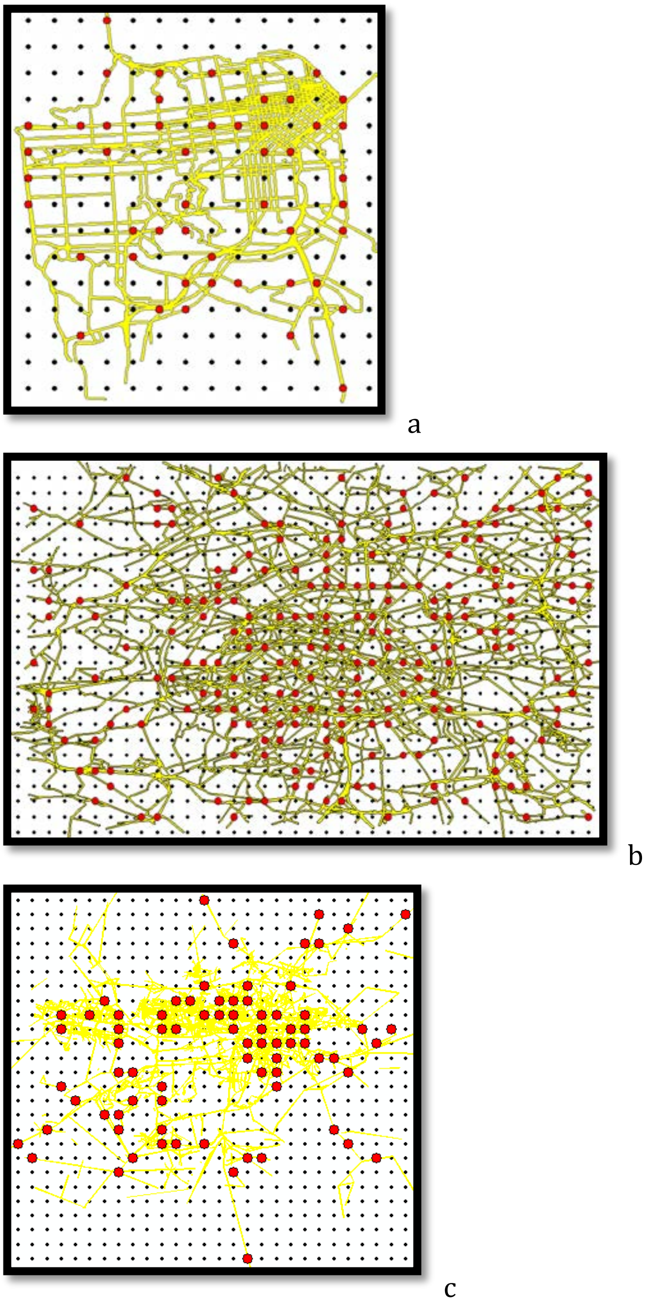

Figure 6. Selection process for the regularly created locations according to their proximity to the transportation networks by using spatial query capabilities of GIS (a→San Francisco (grid network, b→Paris (radial network), c→Ankara (mixed network)

In the final step, origin/destination locations which are relatively far from transportation networks are eliminated and closer ones are maintained to be used as input datasets in "accessibility modeling phase" (see Figure 7).

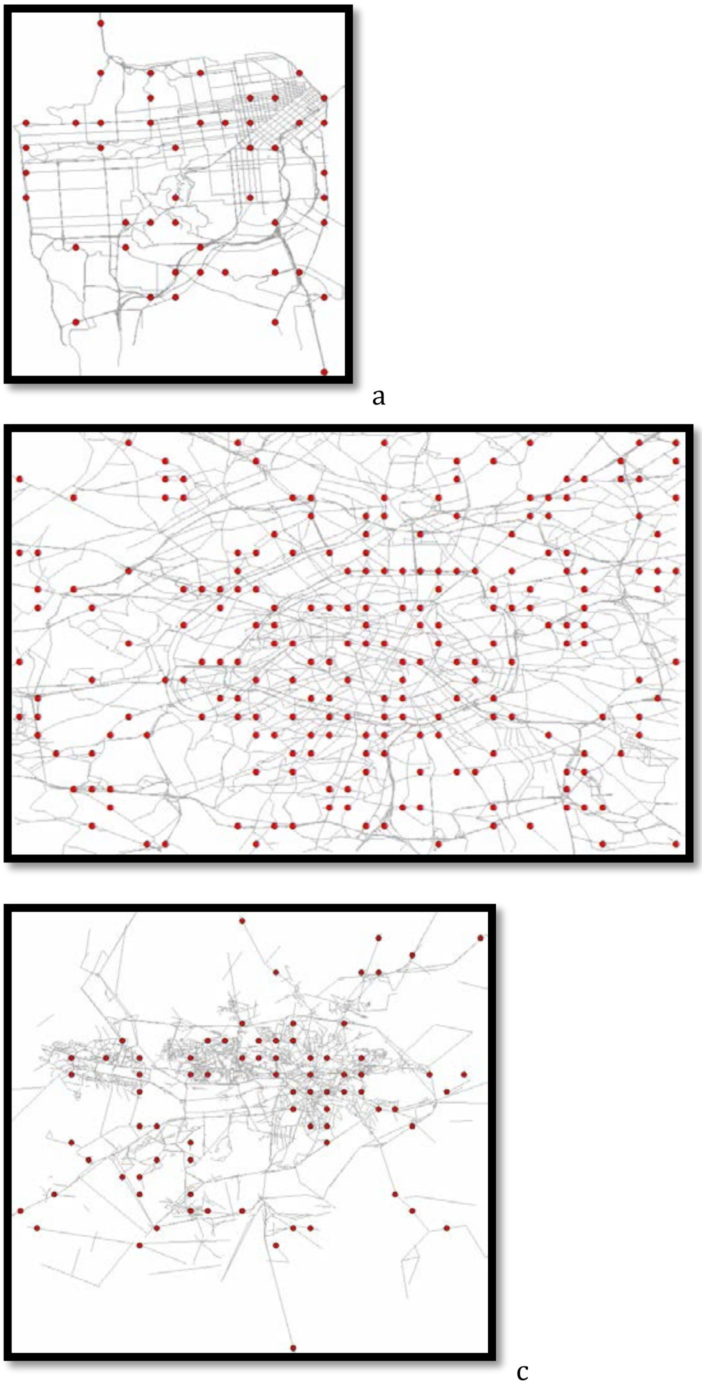

Figure 7. Elimination of origin/destination locations which are relatively far from transportation networks; closer ones are maintained to be used as input datasets in accessibility modeling phase (red locations) (a→San Francisco (grid network, b→Paris (radial network), c→Ankara (mixed network)

Accessibility Modeling Phase

This section covers directness-based accessibility modeling steps in GIS environment. By using the network analysis capabilities of GIS, both Euclidian and network based distances between each of the regularly created origins and destinations on the transportation network is calculated. All of the spatial output

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pairs produced by the model are stored in a spatial database which allows comparison of the Euclidian and network based costs between each of the origins (i) and the destinations (j) on the transportation network. The directness ratio (DR) scores between origins and destinations are calculated by using the "Equation 1", mentioned in the introduction part of the research and stored in the spatial database to be used in the evaluation phase of the model.

All directness ratio (DR) scores are between 0 and 1 which means that the higher the score, the better the accessibility between origin and destination pairs in terms of directness. When the DR score is getting closer to 1, this means that network based cost is very close to Eucledian based cost and the accessibility in terms of directness is very high. When the DR score is getting closer to 0, this means network based cost is far to Eucledian based cost and the accessibility in terms of directness is low.

All calculation steps are also automated in GIS environment in order to create accessibility related decision support tool for the decision makers in terms of directness or circuity.

The part below summarizes the accessibility modeling phase related with the case study area:

By using the datasets obtained/created from data preparation phase, accessibility modeling phase calculates a) Euclidian based distances between each of the origins and destinations on the transportation network b) Network based distances between each of the origins and destinations on the transportation network c) partial and overall directness ratio (DR) scores by using Equation 1.

Euclidian and Network based distances between each of the origins and destinations are calculated by using Origin Destination Cost Matrix calculation capabilities of ArcGIS network analyst. The origin destination locations which are relatively close to the transportation networks are used as input datasets in the proposed model and both Eucledian and Network based costs are calculated for each of the network data sets (see Figure 8, Figure 9).

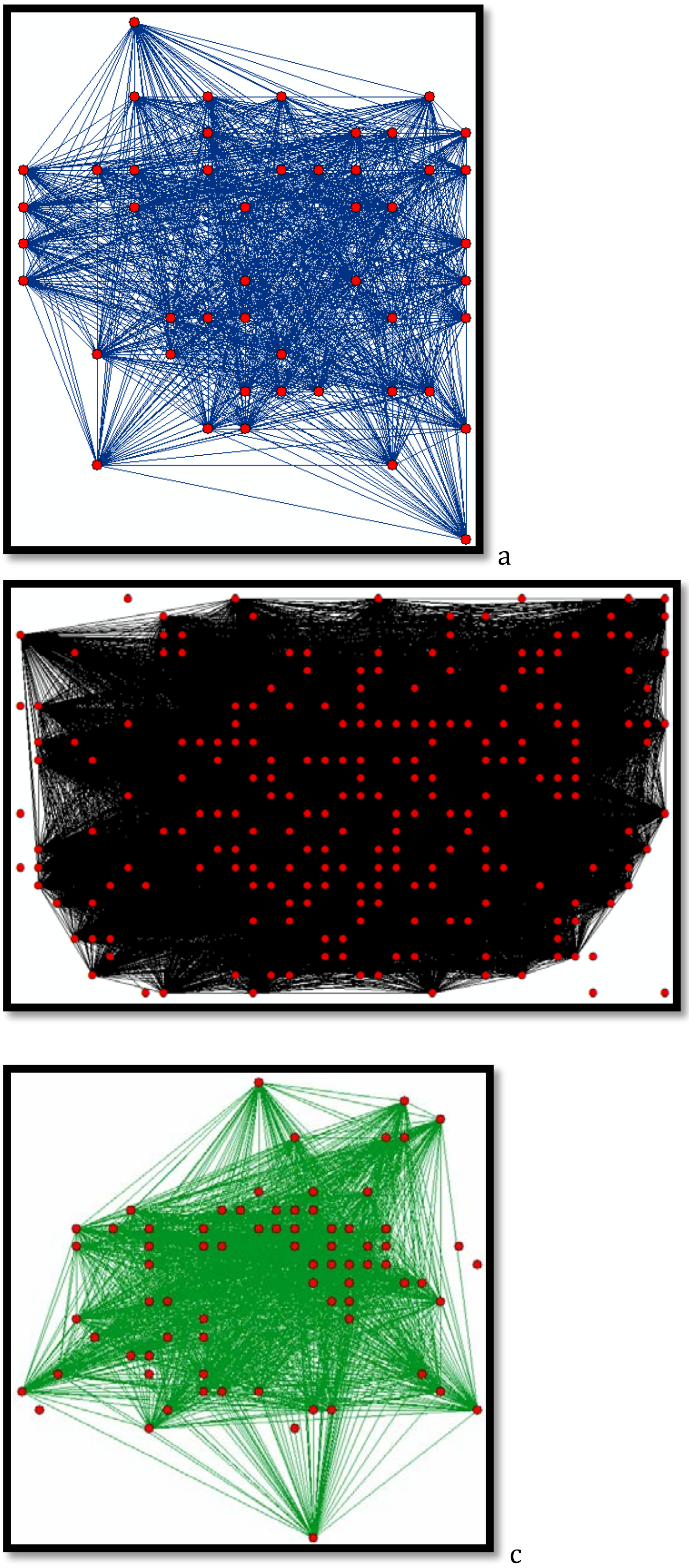

Figure 8. Euclidian based distances between each of the origins and destinations (a→San Francisco (grid network, b→Paris (radial network), c→Ankara (mixed network)

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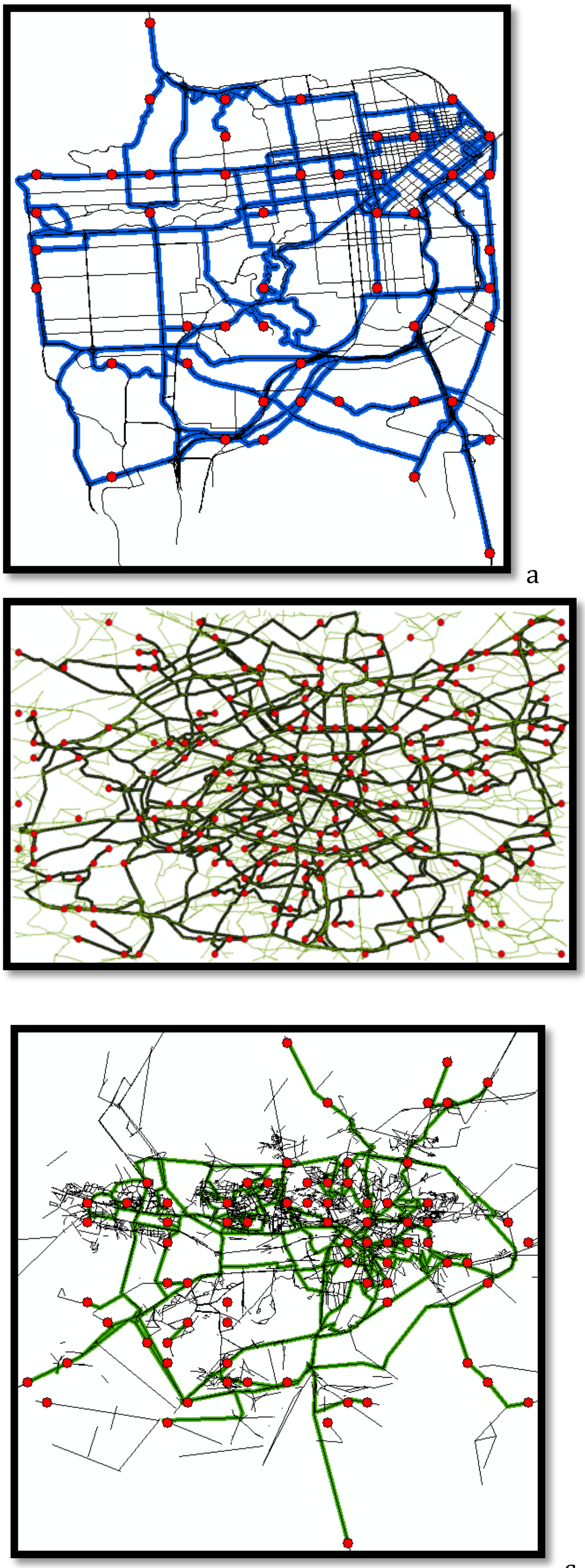


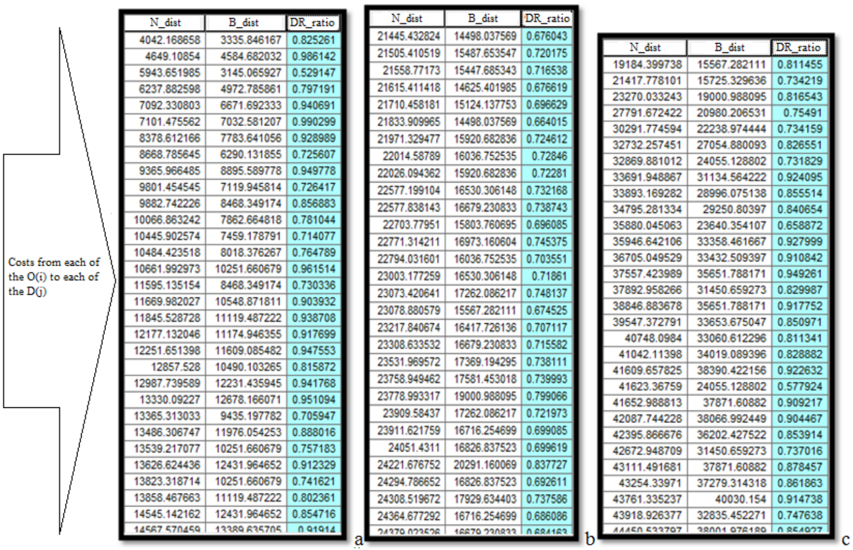
a

b

c

Figure 9. Network based distances between each of the origins and destinations (a→San Francisco (grid network, b→Paris (radial network), c→Ankara (mixed network)

As a final step in this phase, both of the GIS databases of Euclidian and Network based datasets are joined by using "object id" information of origins and destinations. This process enables calculation of partial or overall Directness ratio (DR) scores between origins and destinations in a comparable manner (see Figure 10).



a

N_dist	B_dist	DR_ratio
4042.168658	3335.846167	0.825261
4649.10854	4584.682032	0.986142
5943.651985	3145.065927	0.529147
6237.882598	4972.785861	0.797191
7092.330803	6671.692333	0.940691
7101.475562	7032.581207	0.990299
8378.612166	7783.641056	0.928989
8668.785645	6290.131855	0.725607
9365.966485	8895.589778	0.949778
9801.454545	7119.945814	0.726417
9882.742226	8468.349174	0.856883
10066.863242	7862.664818	0.781044
10445.902574	7459.178791	0.714077
10484.423518	8018.376267	0.764789
10661.992973	10251.660679	0.961514
11595.135154	8468.349174	0.730336
11669.982027	10548.871811	0.903932
11845.528728	11119.487222	0.938708
12177.132046	11174.946355	0.917699
12251.651398	11609.085482	0.947553
12857.528	10490.103265	0.815872
12987.739589	12231.435945	0.941768
13330.09227	12678.166071	0.951094
13365.313033	9435.197782	0.705947
13486.306747	11976.054253	0.888016
13539.217077	10251.660679	0.757183
13626.624436	12431.964652	0.912329
13823.318714	10251.660679	0.741621
13858.467663	11119.487222	0.802361
14545.142162	12431.964652	0.854716
14567.570459	13389.635705	0.91914

b

N_dist	B_dist	DR_ratio
21445.432824	14498.037569	0.676043
21505.410519	15487.653547	0.720175
21558.77173	15447.685343	0.716538
21615.411418	14625.401985	0.676619
21710.458181	15124.137753	0.696629
21833.909965	14498.037569	0.664015
21971.329477	15920.682836	0.724612
22014.58789	16036.752535	0.72846
22026.094362	15920.682836	0.72281
22577.199104	16530.306148	0.732168
22577.838143	16679.230833	0.738743
22703.77951	15803.760695	0.696085
22771.314211	16973.160604	0.745375
22794.031601	16036.752535	0.703551
23003.177259	16530.306148	0.71861
23073.420641	17262.086217	0.748137
23078.880579	15567.282111	0.674525
23217.840674	16417.726136	0.707117
23308.633532	16679.230833	0.715582
23531.969572	17369.194295	0.738111
23758.949462	17581.453018	0.739993
23778.993317	19000.988095	0.799066
23909.58437	17262.086217	0.721973
23911.621759	16716.254699	0.699085
24051.4311	16826.837523	0.699619
24221.676752	20291.160069	0.837727
24294.786652	16826.837523	0.692611
24308.519672	17929.634403	0.737586
24364.677292	16716.254699	0.686086
24379.023526	16679.230833	0.684163

c

N_dist	B_dist	DR_ratio
19184.399738	15567.282111	0.811455
21417.778101	15725.329636	0.734219
23270.033243	19000.988095	0.816543
27791.672422	20980.206531	0.75491
30291.774594	22238.974444	0.734159
32732.257451	27054.880093	0.826551
32869.881012	24055.128802	0.731829
33691.948867	31134.564222	0.924095
33893.169282	28996.075138	0.855514
34795.281334	29250.80397	0.840654
35880.045063	23640.354107	0.658872
35946.642106	33358.461667	0.927999
36705.049529	33432.509397	0.910842
37557.423989	35651.788171	0.949261
37892.958266	31450.659273	0.829987
38846.883678	35651.788171	0.917752
39547.372791	33653.675047	0.850971
40748.0984	33060.612296	0.811341
41042.11398	34019.089396	0.828882
41609.657825	38390.422156	0.922632
41623.36759	24055.128802	0.577924
41652.988813	37871.60882	0.909217
42087.744228	38066.992449	0.904467
42395.866676	36202.427522	0.853914
42672.948709	31450.659273	0.737016
43111.491681	37871.60882	0.878457
43254.33971	37279.314318	0.861863
43761.335237	40030.154	0.914738
43918.926377	32835.452271	0.747638
44450.533797	38001.976189	0.854927

Figure 10. Some examples of calculated directness ratio (DR) scores between each of the origins and destinations (a→San Francisco (grid network, b→Paris (radial network), c→Ankara (mixed network) (N_dist: Network based distance; B_dist: Birdflight / Eucledian distance)

All directness ratio (DR) scores are between 0 and 1 which means that the higher the score, the better the accessibility between that origin and destination in terms of directness.

Evaluation Phase

This section covers calculation of central tendency, dispersion and distribution statistics of the produced DR scores between each of the origins and the destinations on the transportation network by using statistical calculation capabilities of GIS.

The statistics calculated from DR scores are very useful to understand both “overall” and “partial” performance of transportation networks. They also enable to compare the accessibility performance of different networks with each other. When the mean of the DR scores is analyzed as central tendency statistics, the higher mean could mean better accessibility performance for the transportation network. Similarly, when the skewness of the DR scores is analyzed as distribution statistics, the right skewed distribution could mean better “overall” accessibility performance for the transportation network. This means that most of the ratio values are closer to 1 and Network based costs between supply and demand locations are very close to the Euclidian based costs. When the standard deviation of the DR scores is analyzed as dispersion statistics, the lower standard deviation in a right skewed distribution mean better “overall” accessibility performance in a transportation network when

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compared with a higher standard deviation score in a right skewed distribution.

The calculated statistics generated by the proposed model could be widely used by the decision makers who are supposed to deal with accessibility, location/allocation, and service/catchment area related issues by several aims such as; to test the overall/partial performance of the transportation networks, to understand the weakly connected parts of the transportation network and/or to compare the accessibility performance of different networks with each other. Such information is crucial for the decision makers to support accessibility related policy making efforts.

By using statistical calculation capabilities of GIS, the mean, standard deviation and skewness of DR scores are calculated for Paris, FRANCE (radial network), San Francisco, USA (grid network) and Ankara, TURKEY (mixed network) (see Figure 11).

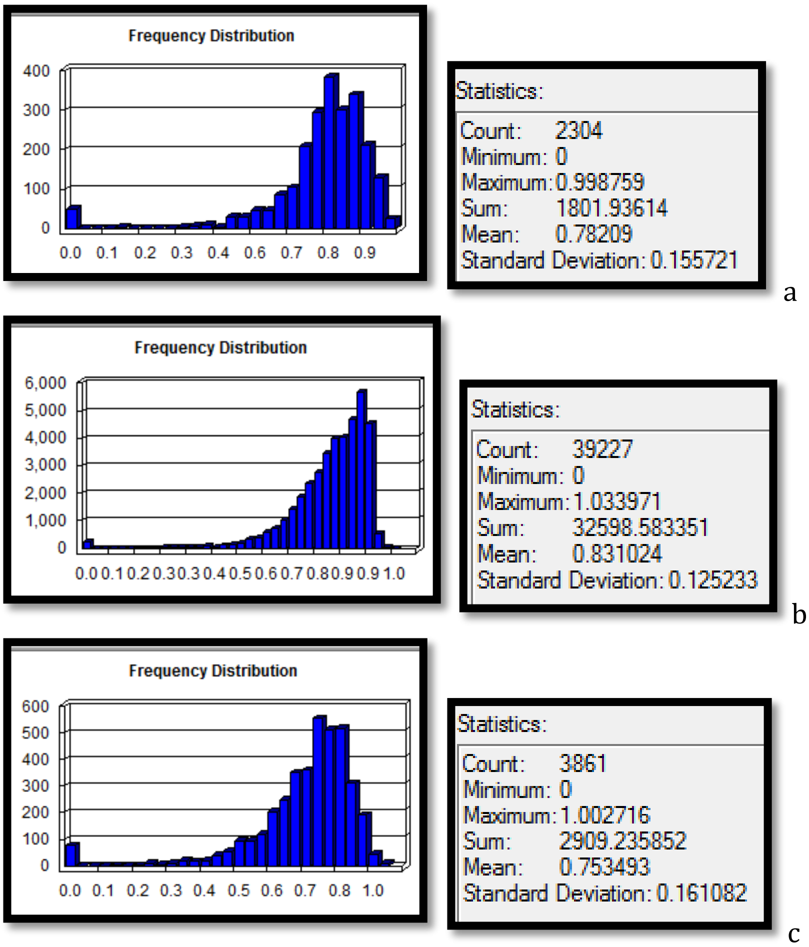

Figure 11. Calculation of central tendency, dispersion and distribution statistics from the spatial DR database between each of the origins and destinations in the transportation network (a→San Francisco (grid network, b→Paris (radial network), c→Ankara (mixed network)

When the mean of the DR scores is analyzed as central tendency statistics, the higher DR mean could mean better overall accessibility performance for the transportation network. According to this information, Paris (radial network) has the highest mean DR score with 0.83, San Francisco, USA (grid network) has the second highest mean DR score with 0.78 and Ankara (mixed network) has the third highest mean DR score with 0.75 value.

Similarly, the skewness of the DR's distribution could also give significant information about the overall accessibility performance of the transportation networks. When the distribution is right skewed (most of the tail is on the left side), this means that most of the DR values are close to 1, most of the network based costs are close to Euclidian based costs and the accessibility between origins and destinations in terms of directness is relatively high. When the distribution is left skewed (most of the tail is on the left side), this means that most of the DR values are close to 0, most of the network based costs between supply and demand locations are far to Eucledian based costs and the accessibility between origins and destinations in terms of directness is low. According to this information, the accessibility in terms of directness can be considered as high in Paris (radial network), San Francisco, USA (grid network) and Ankara (mixed network) on the whole as they all have right skewed DR distribution.

When the standard deviation (stdev) of the DR scores is analyzed as dispersion statistics, the lower standard deviation in a right skewed distribution could mean better "overall" accessibility performance in a transportation network when compared with a higher standard deviation score in a right skewed distribution. According to this information, Paris (radial network) has the lowest stdev with 0.12, San Francisco, USA (grid network) has the second lowest stdev with 0.15 and Ankara (mixed network) has the third lowest stdev with 0.16.

When all of the statistics (the mean of DR's, stdev of DR's and skewness of DR's) are evaluated in an integrated manner, it can be said that Paris (radial network) has the highest overall accessibility performance, San Francisco, USA (grid network) has the secondly highest overall accessibility performance and Ankara (mixed network) has the thirdly highest overall accessibility performance in terms of directness.

As well as the proposed methodology can help decision makers to understand partial/overall accessibility performance of transportation networks in a comparable manner, it also enables to understand the weakly connected parts of the transportation networks. By the help of the proposed methodology, decision maker could demonstrate which of the origin/destination locations have relatively low DR scores and could use this

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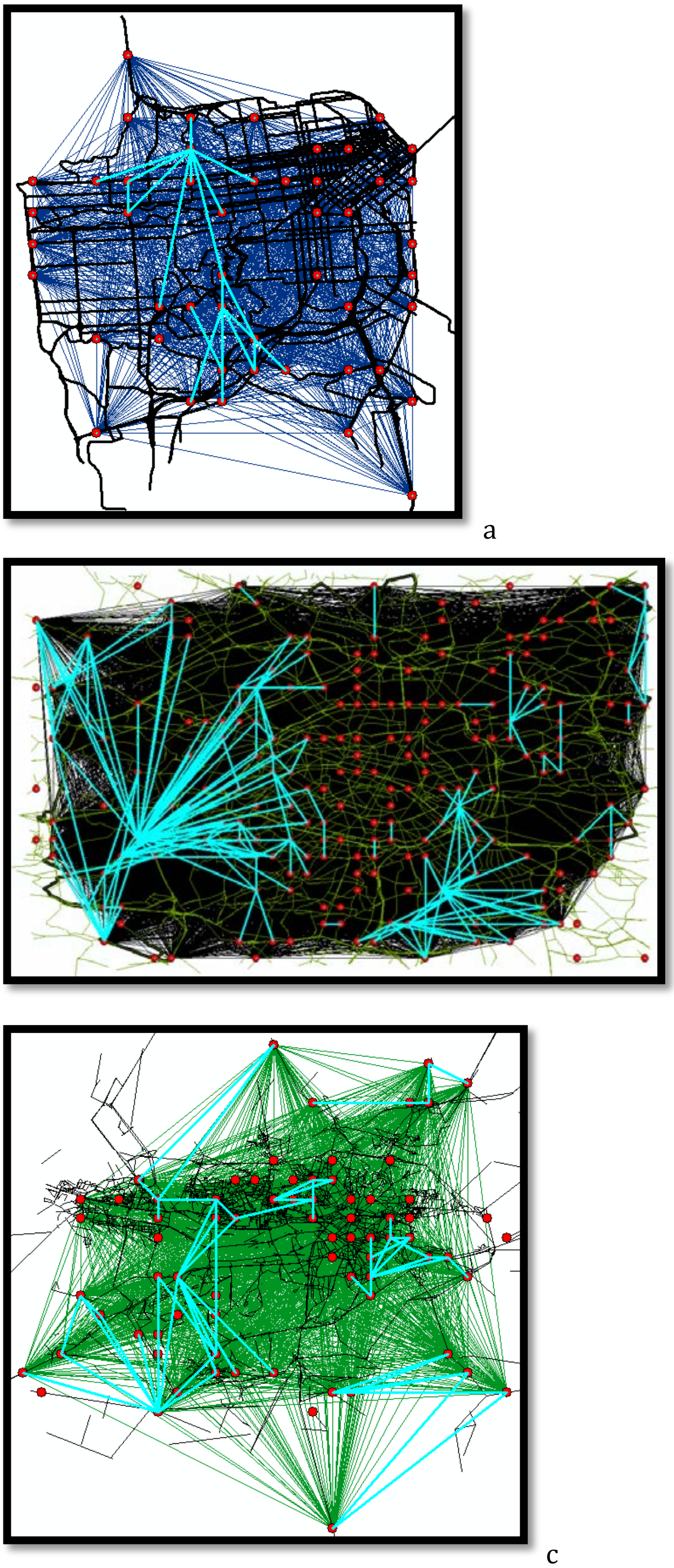
information to define intervention zones and create strategies to increase accessibility between problematic locations. For example the origin destination pairs which have low DR scores (0 < DR < 0.5) are demonstrated as highlighted blue polylines in Figure 12.



a

b

c

Figure 12. The origin destination pairs which have low DR scores (weakly connected parts of the transportation network are demonstrated as highlighted blue polylines) (0 < DR < 0.5) (a→San Francisco (grid network, b→Paris (radial network), c→Ankara (mixed network)

CONCLUSION

Although there are several research and literature that use transportation network directness / circuity measure to understand accessibility level of people, place or transportation networks in a "partial" approach, there has been limited research that integrates transportation network directness / circuity concept into accessibility modeling process in such a way that provide understanding of the "overall" accessibility performance of the transportation networks without losing the local interactions.

Based on this idea, this research proposed a new directness-based accessibility modeling methodology in a simulation logic, in such a way that considers most of the possible origin destination combinations in the network by using the regularly produced virtual origins and destinations on the transportation network and provide understanding of the "overall" accessibility performance of the transportation networks without losing the "partial" interactions.

The basic advantage of the proposed directness-based accessibility modeling methodology is that; the proposed methodology could produce directness-based accessibility measures in a simple, comparable and easy to operate manner and most importantly, it is considerably realistic to understand overall and/or partial performance of transportation networks as most of the possible origin/destination scenarios could be represented in the model without a need for additional supply/demand or origin/destination data.

By considering regularly produced virtual origins and destinations on the transportation network, the proposed methodology could produce "travel time/distance" based accessibility measures (DR scores) that could operate without a need for real time supply/demand or origin/destination data. The advantage of using a virtual regular data set instead of real time data is that; it is more simple, easy to operate and most importantly, more realistic to understand performance of transportation networks as most of the possible origin/destination combinations could be represented in the proposed model.

Although the proposed methodology is applied in 3 cities with different types of transportation network which are Paris, FRANCE (radial network) and San Francisco, USA (grid network) Ankara, TURKEY (mixed network), the main focus of the case study is not to evaluate specific accessibility conditions in a

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detailed manner but to provide a methodological discussion about the proposed directness based accessibility modeling process in order to able to demonstrate the performance, efficiency and usability of the proposed model.

In the light of the results obtained, it can be said that the aim of the research was reached. The outputs of the model could be widely used by the decision-makers who are supposed to deal with accessibility, location/allocation, and service/catchment area related issues by several aims such as; to test the overall/partial performance of the transportation networks, to understand the weakly connected parts of the transportation network and/or to compare the accessibility performance of different networks with each other.

The detail, type and complexity of the used transportation network data and regularly created virtual origin (demand) and destination (supply) locations can be modified by the decision-makers according to the aim, the budget, and the specific detail needs of the study. For example; the proposed model can be operated by several types of networks such as public transportation, pedestrian, bicycle, car etc. and/or by randomly created origin destination pairs. As the real-life transportation supply and demand relationships may not be homogeneously distributed throughout an entire city or there may even be more important zones or flows in some areas than others within the city, the proposed model can also be operated by using real-life origin destination datasets instead of using regularly created virtual origin destination pairs and/or by “different weighted” approaches instead of “equal weighted” approaches, which could also be seen as some suggestions for the future work.

Finally, it must be underlined that; the main focus of the research brings about certain assumptions for other factors that affect the performance of the transportation network. Although there are many factors that could affect the accessibility performance of the transportation network such as; topography (flat / sloped city), landuse characteristics (mono-centric / poly-centric city), traffic density, supply and demand conditions (distribution of the industry, retail, housing etc), the proposed model provides understanding of the accessibility performance of the transportation networks from only “directness/circuity” point of view. The main focus of the research is not to evaluate specific accessibility conditions or transportation network performance in a detailed manner but to provide a methodological discussion about the proposed directness based accessibility modeling process. Hence, the results of the proposed model should be evaluated by the decision makers in the light of this awareness.

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Resume

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