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Sustainable approach to land development opportunities based on both origin-destination matrix and transportation system constraints, case study: Central business district of Isfahan, Iran

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ABSTRACT

Given that there are restrictions on expanding the infrastructure for the purpose of fulfilling future transportation demand, it is critical to consider the capacity of the existing transportation system and the sustainable extent of development, in order to avoid problems such as traffic congestion and air pollution. In this study, by applying the inverse of conventional transportation planning, which is different from the land-use transportation interaction modeling, land-use limits for each Traffic Analysis Zone (TAZ) are determined as a function of the transportation system capacity. Indeed, this method is applied to examine the trip generation capacity of each TAZ with respect to its trip end values. Comparing the indicated capacity with the current demand for each zone can act as a key tool for urban policy makers and planners to define the spatial distribution of new activities based on the present capacity of the transportation system in the studied area. For this purpose, after selecting the transportation network of the central business district in the City of Isfahan as a case of study, the artificial neural networks solution is used to solve the inverse transportation planning problem.

1. Introduction

Land-use planning deals with diverse activities of land consuming agents such as households, firms, and retail markets each with particular requirements for space and accessibility. Land-use development is affected by many forces involving individuals and organizations in both the public and private sectors. There are various factors in the land development process. These include overall population, economic conditions, individual preferences and life style choices, market conditions, local planning and zoning polices, infrastructure, changing technology, and geographic and topographic conditions (WisDOT, 1996). Uncontrolled urban growth leads to environmental degradation, economic slowdown and a reduced quality of life (Aljoufie, Brussel, Zuidgeest, van Delden, & van Maarseveen, 2016). By regulating land use from the outset, land use planning has significant effects on controlling the expansion of construction land, which is formulated to coordinate the scheduling, spatial distribution, and scale of land growth to achieve sustainable, healthy, and orderly urban development (Zhou et al., 2017).

Among above mentioned factors, transportation systems have a significant impact on development and land use patterns of each city (Dehnavi, Rezvan, Shirmohammadli, & Vallée, 2013). For instance, constructing a new road or widening an existing road will lead to decrease in the travel costs between some zones and then increase in the accessibilities for those zones. Hansen (1959) demonstrated that locations with good accessibility have a higher chance of being developed than remote locations.

On the other hand, a change in the distribution of population and employment causes travel demand variation. New travel demand patterns will lead to new traffic patterns and new bottlenecks. Consequently, underestimating required capacity at some areas and overestimating the usage of transportation infrastructure at other areas might occur (Szeto, Jiang, Wang, & Sumalee, 2015).

Therefore, land-use and transportation strongly interact with each other. This two-way interaction is represented as a feedback cycle in Fig. 1.

Attracting significant research attention, the interaction between land-use and urban transportation is one of the key issues of the sustainable transportation (Bigotte, Krass, Antunes, & Berman, 2010). As some of the important issues in sustainable development, traffic

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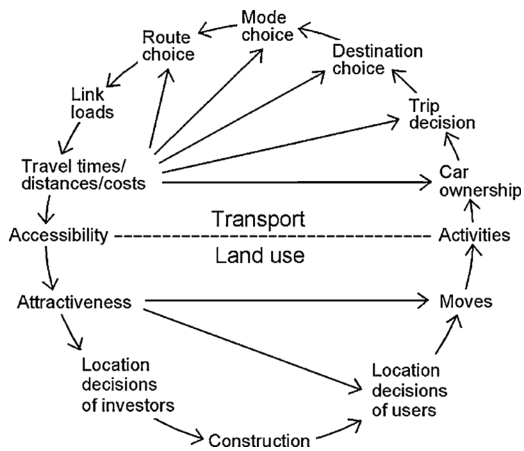

Fig. 1. The land-use transport feedback cycle.
(Source: Wegener & Fürst, 2004).

congestion and air pollution caused by city expansion and motorization, have attracted attention of a lot of researchers and policy makers (Zhu, Li, Liu, Chen, & Zeng, 2017).

The traffic congestion problem can be examined from two points of view: 1) transportation supply pertaining to the transportation infrastructure of the city like street networks, public transportation system; and 2) unsatisfied transportation demand.

Recently, many innovative solutions have been introduced by planners and urban transportation experts in both fields of supply and demand in order to decrease congestion and air pollution. Supply solutions consist of construction of infrastructure such as new roads and interchanges as well as the implementation of intelligent transportation systems and public transportation enhancements, all of which require substantial budgets. On the other hand, demand alternatives are transportation demand measures, road space rationing and telecommunication, which have a small impact on reducing trips, vehicle kilometers traveled (VKT), and consequently congestion. Although other policies such as congestion pricing, fuel taxes, and emission fines have much stronger influences, they may result in public dissatisfactions. While these strategies have some advantages in a short time, as a long-run policy one should be aware of the extent to which the transportation system can be developed without expectation of significant changes by considering the impact of different land-use location mixtures on the trips generated from TAZs (Middlesex Somerset Mercer Regional Council, 1988). Clearly, the number of zonal trips produced from and attracted to each zone should be evaluated before planning and locating land uses to prevent problems of congestion and air pollution. Therefore, there is an urgent need for a study to facilitate sustainable planning of land uses and new developments to lessen problems without requiring infrastructure expansion to boost road networks capacity resulting in saving resources.

It is worth noting that, in the conventional transportation planning, given land-use patterns, modeling is initiated by considering several factors such as employment and population; thus traffic volumes of links can be predicted (Sheffi, 1985). On the contrary, to obtain land-use limits from traffic volumes, it is necessary to apply the inverse the transportation planning. It should be noted that this problem is different from origin-destination (OD) determination which concerns individual elements of the OD matrix. It is also unlike LUTI models such as DRAM-EMPAL or MEPLAN that are capable of establishing reciprocal linkages between land-use and transportation models. For this reason, in this study, our focus is on the inverse transportation planning method in which zonal trip ends (i.e. the number of trips produced from or attracted to each zone) have been estimated directly from transportation system features.

The remainder of this paper is organized as follows: the literature review is presented in Section 1; definition of the purpose and the case of study are expressed in Section 3. The methodology and the results are presented in Section 4 and discussion, conclusions and future studies finalize the paper in Section 5.

2. Literature review

The future for all cities depends on its existing conducts. Having a sustainable city is imperative in this rapid world urbanization. With the rapid urbanization process, the size of cities is increasing and the demand of travel is growing (Krüger, 2012; Naphade, Banavar, Harrison, Paraszczak, & Morris, 2011; Pérez, Carrillo, & Montoya-Torres, 2015; Thinh, Arlt, Heber, Hennersdorf, & Lehmann, 2002). Sustainable development of cities, needs integration of land use and transportation decisions. According to Dur and Yigitcanlar (2015), this type of integration is considered as an integral part of sustainable urban development. Many researchers have been focused to integrate land-use and transportation planning. This perspective in transportation literature is known as land-use transportation interaction (LUTI) models. The advantage of these models is in their ability to evaluate land use and transport planning in an integrated and consistent system (e.g., see Waddell, Ulfarsson, Franklin, & Lobb, 2007).

There exist some studies on modelling the integrated land use and the transportation system. Beginning 1990s, the number of available LUTI models and their implementation in real world is on a rise. To some authors the following decades are known as the golden age of LUTI modelling (Jones, 2016). A great portion of these models are reviewed by Wegener (2004), who selected 20 LUTI models based on different modelling techniques. The Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability (PROPOLIS) research project (Lautso et al., 2004), financed by the European Commission, evaluated different scenarios in various study areas to simulate the effects of the relationship of transport and land use in terms of pollution, social impacts on health and economic well-being in general.

The status of research and practical applications regarding LUTI models is good. Some of the contemporary subjects that are being addressed by researchers consist of: microsimulation, adopting high-resolution models with greater data requirements (Wegener, 2011); the integration of LUTI models and activity based models (Acheampong & Silva, 2015); adopting LUTI models in assessing the environmental impacts; simulating the complete dynamics of urban systems instead of instant transition into points of equilibrium thereof (Simmonds, Waddell, & Wegener, 2013); applying spatial decision models or the interrelations with other modelling paradigms like cellular automata or agent-based models (Timmermans, 2003) and applying the spatial-econometric techniques (dell'Olio, Ibeas, & Cordera, 2016). The LUTI models have been reviewed by a number of researchers with different perspectives (e.g., Chang, 2006; Iacono, Levinson, & El-Geneidy, 2008; Wegener, 2014; Acheampong & Silva, 2015; Cordera, Ibeas, dell'Olio, & Alonso, 2018).

Although LUTI models can overcome existing shortages in conventional four-step models, the complexity of the fluid theoretical underpinnings of such models, as well as other challenges, points to some drawbacks; as an indication, integrated land-use and transportation planning have not proceeded as fast as expected (Emberger, Shepherd, & May, 2008; Nijkamp, Borzacchiello, Ciuffo, & Torrieri, 2007).

While development and land use do change over time to facilitate new functions and activities in the cities, insufficient financial resources to build new transportation infrastructure or the existence of cultural and traditional textures, prevent major projects' implementation (Vialard & Carpenter, 2015). Accordingly, for sustainable development of cities, researchers seek to identify land-use limits based on transportation system constraints. This kind of planning approach is referred to as inverse transportation planning.

There are quite a few studies in the field of inverse transportation planning. The interesting idea of deriving land-use limits from transportation usage was presented by Miller and Demetsky (1999) for the first time. They attempted to develop a method to reverse the direction of the typical four-step transportation planning process. Their initial objective was to estimate the OD demand matrix from link volumes to determine the trip ends of zones. However, this model performed too poorly to be of use due to the complexity of estimating the OD matrix based on traffic counts. As an alternative, the authors developed a regression technique to directly estimate zonal trip ends with an acceptable error according to variables such as link volumes, roadway types, travel speeds and the position of a zone relative to others. Nevertheless, their model was more accurate for aggregate predictions for whole the study area than for each zone predictions.

In a more recent study, Sadek and Mark (2003) developed modular Artificial Neural Networks (ANNs) to solve inverse transportation planning to directly predict zonal trip ends from link volumes of the transportation network. They examined the impact of a number of factors including the transportation network size, data variability and the ANNs topology on the accuracy of the modeling procedure and concluded that a modular ANN with one or two hidden layers is capable of directly deriving zonal trip ends from link volumes with adequate accuracy, regardless of the transportation network size and complexity.

3. Definition of the purpose and the case of study

The City of Isfahan with a 260-square-kilometer area, a population of approximately 2 million people and more than 4.4 million trips per day is considered to be the third largest city in Iran. Isfahan is a city with a multitude tourist attractions that are mostly centered in downtown, to which 15% of the city's daily trips are attracted. Recently, the city has been facing shortfalls in the urban transportation sector as well as problems with traffic congestion and air pollution (Ghadirifaraz, Vaziri, Safa, & Barikrou, 2017). An average annual population growth rate of 1.37 percent and a surge in car ownership (330 vehicles for every 1000 persons), in the city of Isfahan have dramatically increased the number of vehicles on streets and highways, ultimately leading to traffic congestion and air pollution. Therefore, the city transportation experts are searching for applicable solutions to relieve the city from these problems.

There are several restrictions in Isfahan's transportation system precisely in the core area of the city, among the most outstanding of which are the inefficient orientation of sustainable urban transportation, fundamental weakness and a shortage of road network given that the transportation network cannot be expanded. Furthermore, the cultural heritage sites located in the central part of the city and the large expenses of releasing real estate for road construction prevent roads from being widened (Salavati, Haghshenas, Ghadirifaraz, Laghaei, & Eftekhari, 2016). Moreover, the historical and valuable texture of the city has led experts to seek solutions based on substantial effects of land-use configurations on the transportation system to solve the city's traffic issues. In this regard, for optimal allocation of available city resources, it is essential that authorities implicate and implement appropriate policies to address these challenges. In Isfahan, policies such as road space rationing and public transportation enhancement have been implemented as short-term solutions and have had relatively positive effects; however, there is an urgent need for proposing a long-term strategy that is more effective in mitigating traffic problems.

Hence, a policy can be proposed to control the city development concerning land-use limits especially for the central business district (CBD) of Isfahan given the current transportation infrastructure constraints. Thus, the objective of this study is to determine land-use limits, in line with the transportation system characteristics and road volumes, using the inverse transportation method in order to afford a favorable future traffic situation.

4. Methodology

The methodology applied to solve the inverse transportation planning problem is outlined in below:

1. As the sample of the study, a subnetwork is extracted from the transportation network in Isfahan. Since the 2000s, the Department of Traffic and Transportation has deployed an excellent transportation model for the city.
2. For data generation, to train the ANN, in the first step, numerous randomly produced OD demand matrices are generated using the GAUSS software. Afterwards, these OD demand matrices are assigned by the transportation planning software EMME/4 individually and their deriving link volumes are recorded; thus, the trip ends for each TAZ can be calculated.
3. Taking advantage of the data prepared in the previous section (i.e., OD demand matrices and their projected link volumes), ANNs are trained using MATLAB software.
4. Applying inverse transportation modeling, the zonal trip ends as the desired output, are obtained via the ANN computations according to practical capacity of the links as input data. Finally, the computational results, including zonal desired trip ends are compared to the actual capacity for each TAZ by taking into account the existing transportation system characteristics. The comparison helps to categorize TAZs in terms of their development potential: TAZs with development prohibition, TAZs with very limited development permission and TAZs with development potential are determined.

Since the ANN is used in the proposed methodology, ANNs is introduced briefly before describing details of the proposed methodology.

4.1. Artificial Neural Networks

ANNs is a computational model inspired by the way biological neural networks in the human brain process information, organized in layers. ANNs are among the most common machine learning algorithms due to their flexible ability to work with complex data and nonlinear functions to a certain degree of accuracy by adjusting the network weights (Karlaftis & Vlahogianni, 2011). One of the most important types of ANNs is the Multi-Layer Perceptron (MLP) consisting of three layers: 1) the input layer, which involves a set of nodes representing input variables, 2) the output layer representing the vector of computational results and 3) the hidden layer or layers to perform computations and transfer information as illustrated in Fig. 2.

ANNs are known as a robust modeling technique for their ability to recognize patterns and relate a system's inputs to its output without having a specific knowledge of the system functions. With respect to pattern recognition and complex large-scale transportation systems with uncertainty, as an adaptive method, ANN modeling is regarded as an effective tool for solving numerous transportation problems (Abdelwahab & Abdel-Aty, 2002; Dougherty, 1995; Ye, Osman, Ishak, &

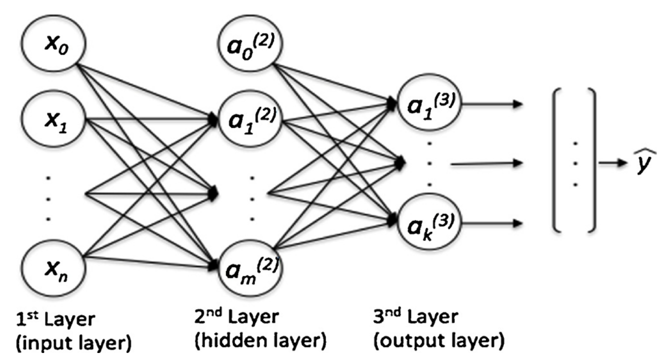

Fig. 2. General Structure of ANNs Model.

Hashemi, 2017). Also, this modeling approach enables performing sensitivity analyses using different values of noise or unknown information in transportation issues (Lorenzo & Matteo, 2013). Having established a direct relationship, ANNs are extensively applied in the OD matrix estimation based on traffic counts (Gong, 1998; Kikuchi & Tanaka, 2000; Mussone, Grant-Muller, & Haibo, 2010). Moreover, ANNs are a good computational tool for solving the inverse transportation problem (direct projection of land use limits from infrastructure attributes), because they are capable of relating a system's inputs to its outputs with no prior knowledge of how the system functions. This is the result of observing many system responses to various changes in input parameters to create a general model that can evaluate specific scenarios (Rodrigue, 1997).

4.2. Step 1: subnetwork selection

The present transportation network of the City of Isfahan includes 186 traffic analysis zones, 2299 nodes and 6583 links with a total length of 2227 km. The composition of link function types is as follows: 410 km collector; 379 km local; 833 km arterial; 107 km highway; 24 km freeway; and 68 km include ramps and loops. It is evident that this transportation network can account for a large-scale one. In Fig. 3, an illustration of Isfahan's transportation network can be seen.

Given the establishment of land uses with high density and diversity which mainly include service and commercial activities, the CBD of Isfahan, which is surrounded by the second traffic ring of the city, encounters various traffic problems since it receives a great share of the city's travel demand. As previously mentioned, due to certain restrictions, it is infeasible to expand the road network and the infrastructure in the CBD of Isfahan. Therefore, this region is selected as the case of this study to derive land-use limits as a function of traffic volumes regarding the present transportation system capacity. Having 44 TAZs, 347 nodes and 907 links with a total length of 257 km, the CBD region is limited to Bozorgmehr and Sajad Streets in the east, Modaress and Bahonar Streets in the north, Kharazi Highway in the West and Saadatabad and Daneshgah Streets in the south, as shown in Fig. 4.

To facilitate the study, the EMME/4 software is used to extract the CBD network from the city's transportation network, which is called a subnetwork, as shown in Fig. 5. The OD matrix of the subnetwork, known as traversal, is extracted from the OD demand matrix in Isfahan's transportation network. The dimensions of the traversal matrix

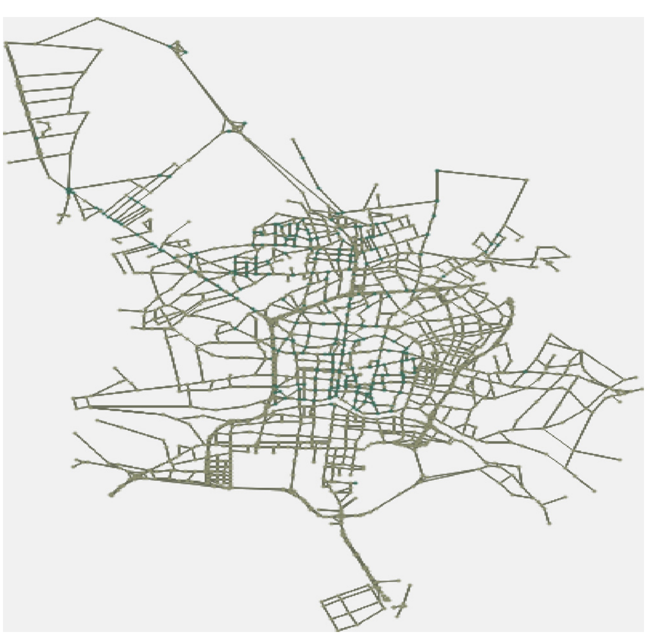

Fig. 3. Transportation Network of Isfahan City.

are obtained from CBD traffic analysis of the zones in addition to boundary TAZs. Involving 44 TAZs, the total daily trips in traversal matrix is 655,058 and this value equals 4,417,717 for Isfahan's OD demand matrix. It is worth noting that, the peak hour traffic volume of the subnetwork is 15 percent compared to its 11.5 percent share of the total roads length of the city. Fig. 6 illustrates traffic volumes resulting from traffic assignment of traversal OD matrix of the subnetwork.

4.3. Step 2: data preparation

In order to prepare the proper data needed to train the ANNs to solve the inverse transportation problem, a large number of OD matrices are produced from the current traversal OD matrix of the subnetwork. Randomly generated OD matrices are produced by adding noise values of ± 20% to the value of each cell of the basic OD matrix with the GAUSS program. This helps the ANN model to be able to solve the objective problem when there is a change in the relative values of the OD matrix. A total of 1000 OD matrices are generated from the CBD transportation network. The GAUSS program is also applied to run the transportation planning software, EMME/4, which is used to assign each generated OD matrix to the corresponding transportation network, resulting in link volumes. Hence, the data required to train the ANN is generated. It should be noted that centroid connectors are hypothetical links added to a transportation model to connect the centroid of the traffic analysis zones to the nodes in the network (Friedrich & Galster, 2009). These links are excluded because including them in the input data complicates trip ends prediction from traffic volumes. Consequently, a 44-element input vector corresponding to the tip ends for 44 TAZs of the network and a 907-element output vector giving traffic volumes of links are prepared to train the ANN.

4.4. Step 3: train of ANNs

Designing ANN topology is one of the important parts of model development. The applied topology in this study is a modular ANN with one hidden layer. Modular feedforward networks are special types of MLP without a full interconnection between layers, which accelerate training and reduce the number of training examples required to reach a certain degree of accuracy (Pham & Liu, 1995). The ANN model is developed with MATLAB using the training data from the foregoing section. The data are categorized into 3 groups of the training data set (70%), the validation data set to test the ANN performance (15%), and the data set for the test (15%).

Fig. 7 exhibits a scatter plot representing the predicted versus actual trip ends, where the 45° line shows an ideal fit. Obviously, the closer data plotted to the line, the better the computed data estimates trip end values. Fig. 7 implies that data fit closely to the 45-degree line. Additionally, the R2 value of 0.77, indicating goodness of fit, can be acceptable especially in the field of transportation modeling. This can indicate that The ANN model is able to appropriately derive zonal trip ends from link volumes of the transportation network.

The previously trained and validated ANN model is applied to solve the inverse transportation planning to capture a relationship between link traffic volumes and the zonal trip ends. To do so, loading all links of a subnetwork to the existent capacity level of the transportation network, expected results of the ANN model that correspond to total trip ends for each TAZ, are determined. For this purpose existing roads in the studied area are categorized into three groups according to their function types: local, collector and secondary arterial. Table 1 represents the practical capacity of 1-meter width of subnetwork links based on their function types.

Considering the fact that links in each of the aforementioned function type category have a practical capacity for each 1 m of width, the total capacity of the subnetwork is calculated (IUT Technical Report, 2008). It is observed from the traffic assignment, that the total peak hour volume of the links in the subnetwork is greater than the practical

Fig. 4. Map of the Central Business District in Isfahan City.

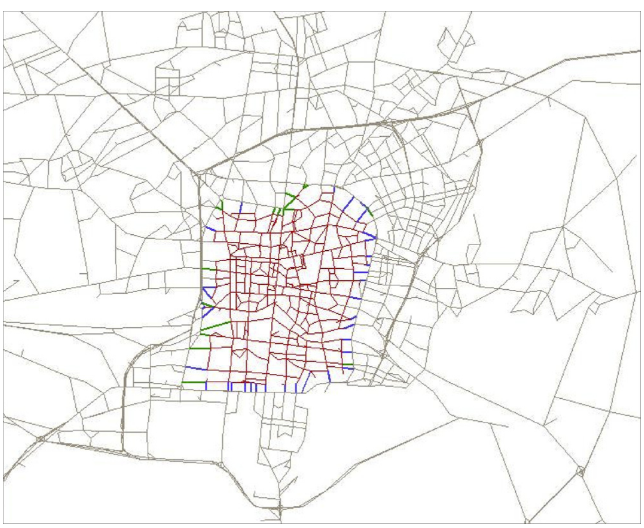

Fig. 5. Transportation Network of CBD.

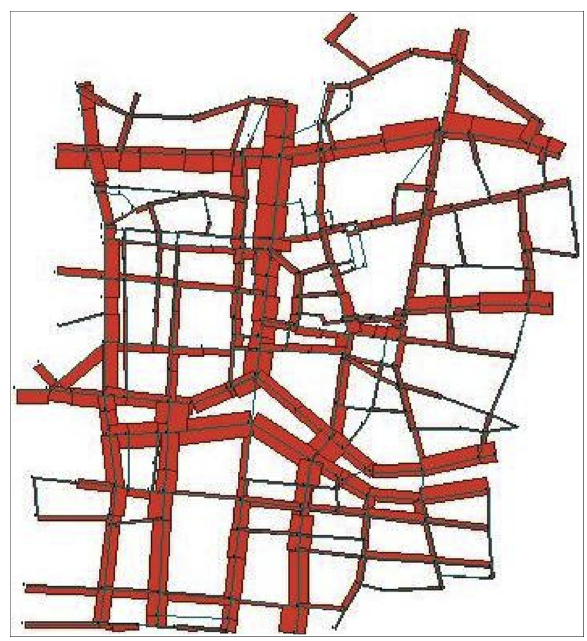

Fig. 6. Link Volumes Resulting from Traffic Assignment of CBD OD Matrix.

capacity of links up to 26 percent causing serious problems which emerge as overloaded TAZs with multiple bottlenecks and traffic congestion.

4.5. Step 4: computational results

Identifying land-use limits for the TAZs of the studied area as the main purpose of this study, the projected trip ends capacity of each TAZ obtained from the ANN model which addresses the constraints of the current transportation system are compared to its actual trip ends. Implying the development opportunity states of CBD TAZs, the comparison results are illustrated in the figures below. Fig. 8 displays the differences between the designated and existing total tip ends for each TAZ. Negative values specify the overloaded TAZs where intensity level are illustrated by colors. On the other hand, positive values indicate TAZs with the capacity of development. Fig. 9 exhibits TAZs with serious development limitations where the brown color represents TAZs without the possibility of further development due to construction and infrastructure extension restrictions caused by the presence of various historical places and monuments (e.g., Naghshe Jahan Square). TAZs with potential development opportunities are identified in Fig. 10 where the green color shows TAZs with the first priority of development.

In order to present the implementing the proposed method to achieve the sustainable development of Isfahan according to development opportunities and constraints in Traffic zones, two scenarios regarding the horizon year of the comprehensive urban plan of the city (2025) were defined and simulated in the EMME/4 software. In the first

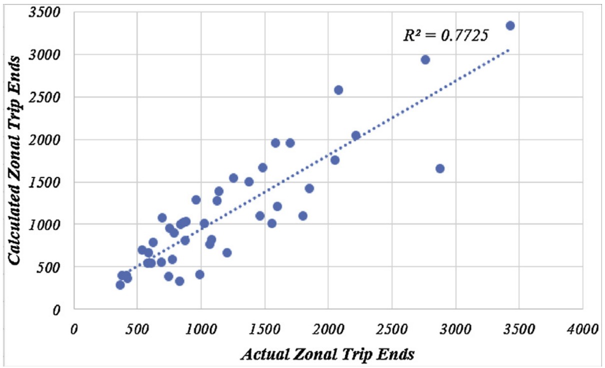

Fig. 7. Computed Versus Actual Zonal Trip Ends for the CBD Transportation Network.

Table 1
Practical Capacity for 1 m Width of Different Link Types of CBD.

Link Function Type	Capacity(pcu/hr)
Local	100
Collector	165
Secondary Arterial	210

scenario, regardless of the transportation system constraints it is assumed that development in traffic zones in the CBD area will occur in the line with the current urban comprehensive plan of the city until the horizon year of 2015. However, the second scenario, in which development opportunities and limitations in TAZs were considered, is defined to achieve sustainable development in Isfahan based on the proposed methodology in this paper. Table 2 shows the results of traffic assignment and the extraction of environmental and traffic sustainability indicators including fuel consumption, pollutant emissions, congestion and total travel time.

According to Table 2 and comparing two scenarios, by applying the second scenario in which development were planned based on transportation constraints, growth rates were decreased for gas consumption from 17.53 to 8.71 percent, and for gasoline consumption from 13.30 to 6.50 percent. In addition, growth rates were declined for CO production from 15.62 to 6.62 percent, for HC production from 19.93 to 9.63 percent, for NOX production from 13.28 to 5.86 percent for congestion index from 17.83 to 7.64 percent, and for total travel time of the entire CBD region from 12.28 to 3.97 percent. These results indicate the successful performance of the proposed model in providing appropriate policies to step towards sustainable development in Isfahan. Fig. 11 illustrates these results.

5. Discussion and conclusion

Rapidly obtaining worldwide attention as a promising response to the challenges of sustainability, the concept of sustainable city development has come to the fore. In this line, current discourses in urban and academic circles continue to concentrate on the role of sustainability in urban and development planning to respond to the substantial challenges arising from the rapidly evolving urbanization as well as the unsustainability of existing form of cities. These Challenges which mostly associates with unceasing urban growth are infrastructure development and management, increased pollution, increased transport needs and traffic congestion, depleting energy resources, public safety and health decrease due to the density of urban population and the intensity of related economic and social activities, worsening by the inefficiency of the built environment, inappropriate urban and development planning (Bibri & Krogstie, 2017).

In sprawling cities like Isfahan, urban sustainability can be achieved by allowing development to be happened upon the potential of a site. Potential can be found in the availability of land that creates

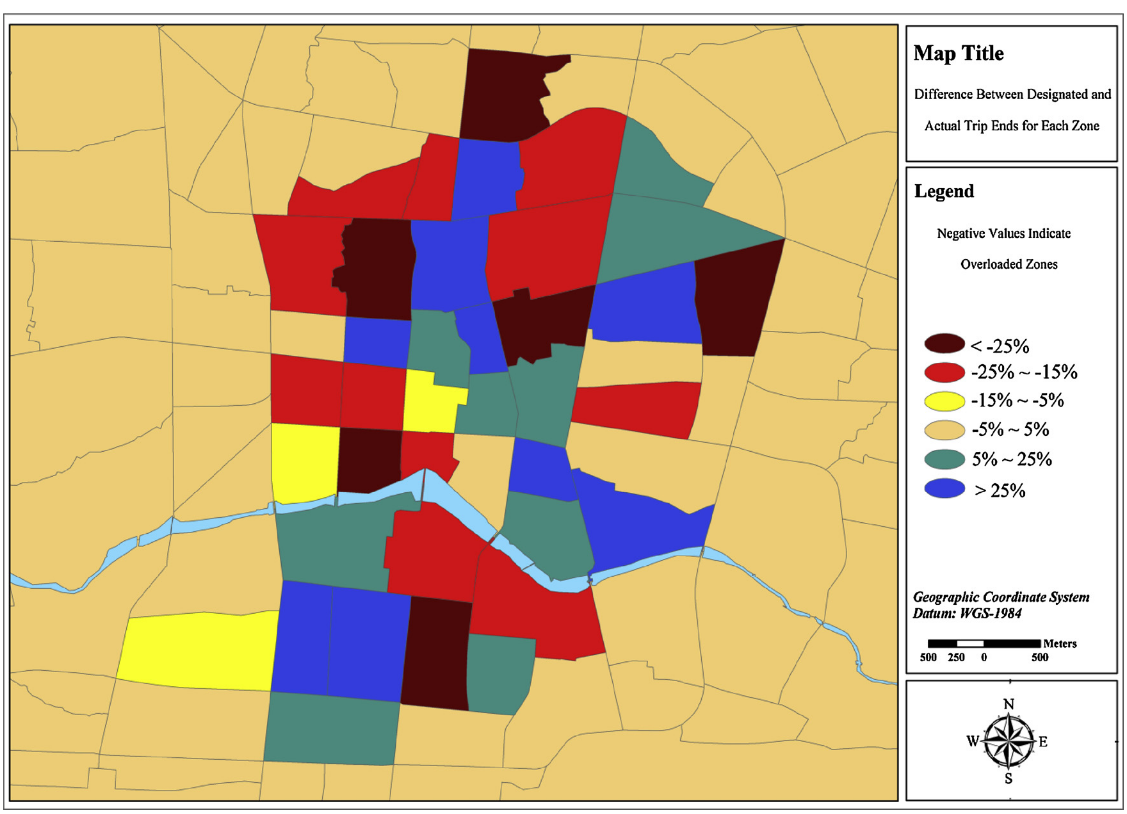

Fig. 8. Identification of TAZs Based on Differences Between Designated and Actual trip Ends for Each of Them.

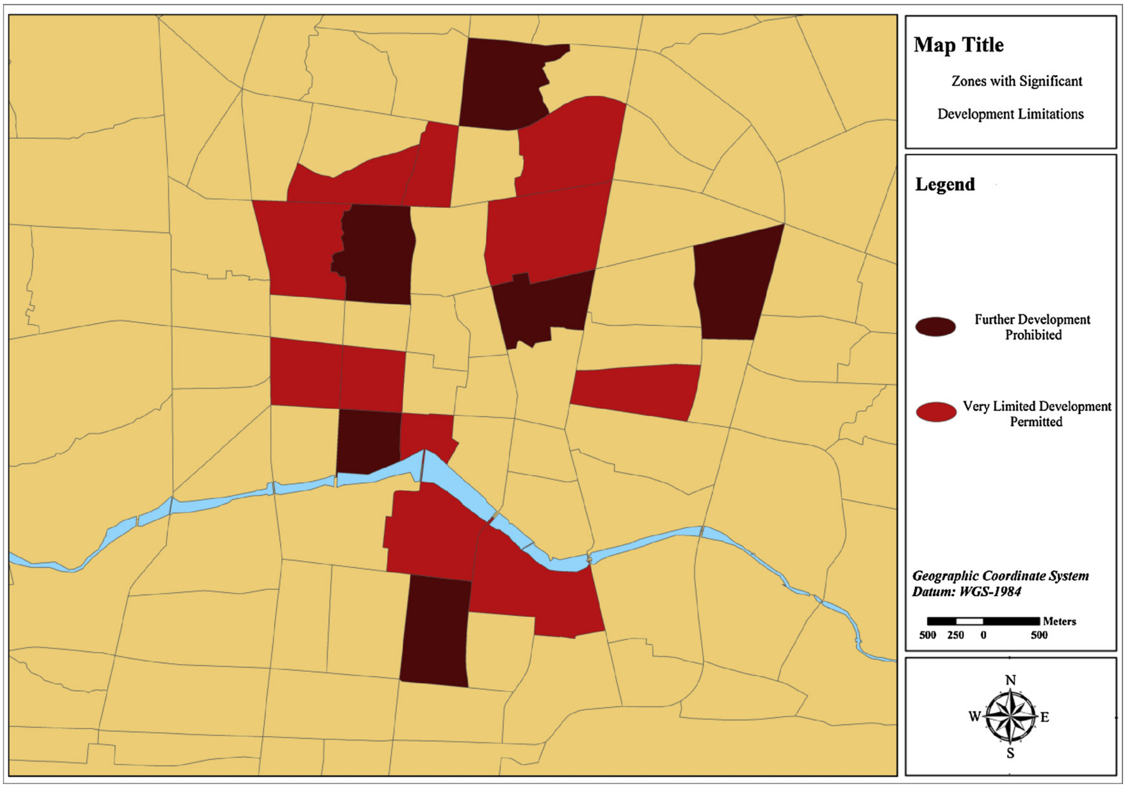

Fig. 9. Identification of TAZs with Significant Development Limitations.

opportunities for fresh development. But the capacity of the current transportation infrastructure in Isfahan has not aligned with escalation of automobile usage, so the majority of roads carry more traffic volume than they were designed to satisfy, mostly because of the fact that the financial resources available to build more transportation infrastructure are insufficient to meet this increased demand. Furthermore, the city of Isfahan has compact morphology especially in the CBD, the area with cultural and traditional texture in which numerous monuments with significant architectural and historic values are scattering. Hence, In spite of deficient and inaccessible transportation network consisting of narrow streets and dead-end allies in CBD region of the city; heritage preservation organization applied jurisdictions to confine

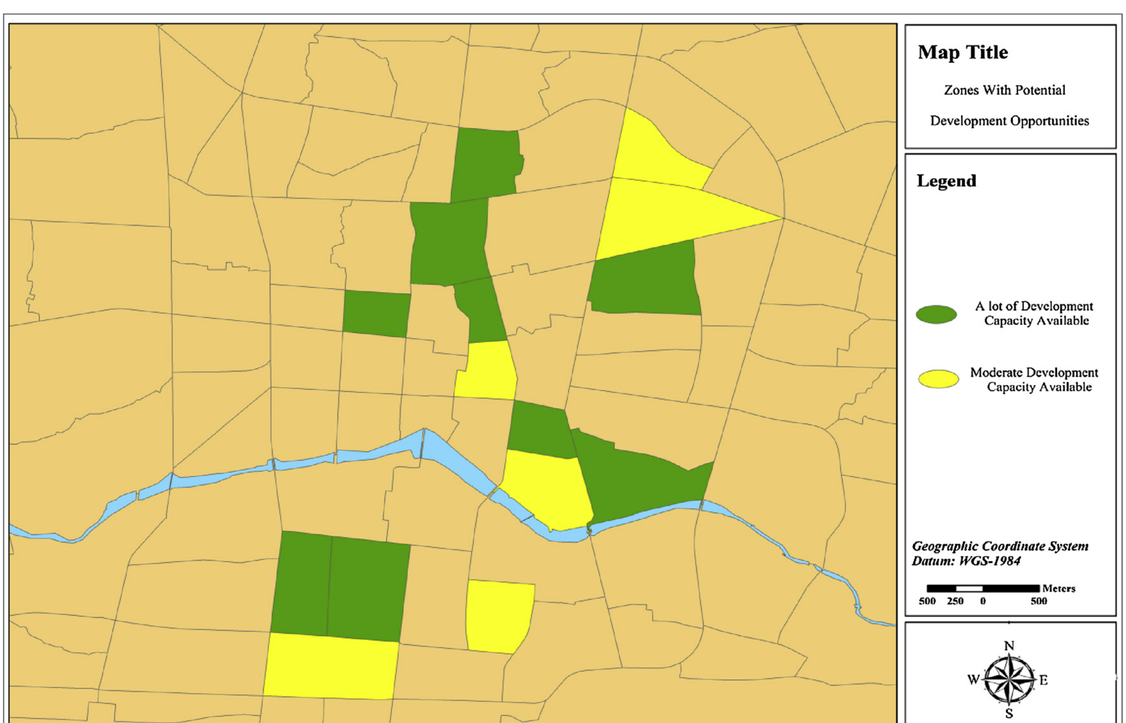

Fig. 10. Identification of TAZs with Potential development opportunities.

Table 2
The results of traffic assignment and the presentation of sustainability and traffic criteria (at morning peak hour in CBD).

Criteria		Current State (2018)	Future State (2025) Without any Constraint	Future State (2025) Based on Existing Transportation system Constraints	Growth Rate for Future (2025) without any Constraints (SCN1)	Growth Rate for Future (2025) based on Existing Transportation system Constraints (SCN2)
Fuel Consumption (Liter)	Gas Consumption	36980	43463	40203	17.53%	8.71%
	Gasoline Consumption	17858	20233	19018	13.30%	6.50%
Total Pollutant Emissions(kg)	CO	14248	16473	15190	15.62%	6.62%
	HC	1505	1805	1650	19.93%	9.63%
	NOX	640	725	678	13.28%	5.86%
Congestion (t/t0)		1.57	1.85	1.69	17.83%	7.64%
Total Travel Time (veh-hr)		8003	8985	8320	12.28%	3.97%

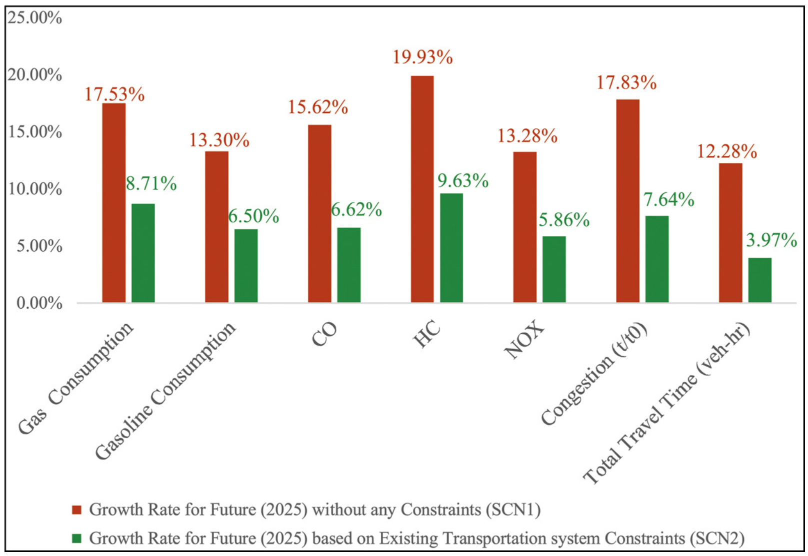

Fig. 11. Comparison of criteria growth between two Scenarios in 2025.

transportation infrastructure development in the CBD, believing these sort of development promote vehicles, interrupts urban life and demolish historic and cultural continuity and texture of the city. In light of this, given all of aforementioned matters and limitations, it is becoming increasingly difficult to construct new or even upgrade transportation facilities; hence, it is reasonable to deem this infrastructure as more fixed than have been considered in the past. Accordingly, for sustainable development of the city, this research endeavored to identify land-use limits based on transportation system constraints to determine just how much development can be accommodated by present transportation infrastructure without expectation of substantial changes and investments in future.

There are several land-use policies that are being considered in order to decrease the side effects of congestion (Deakin, 1991). Among the most important of these is the coordination of land-use and transportation plans. It is argued that effectively applying comprehensive controlled strategies such as sustainable growth and constraints on roadway expansion may contribute to more than 15% decrease in future regional vehicle traffic and associated mobile emissions (Yang, Ng, Xu, & Skitmore, 2018). Thus, to identify the amount of development that can be sustained; the inverse transportation approach is applied to define land-use patterns for an optimal spatial distribution of new activities to prevent traffic jams. Finally, CBD TAZs with development limitations are identified where opportunities of development should be prohibited or tightly limited. Besides, TAZs with the potential and priority of development are determined to support current circumstances in the CBD which can act as an anti-sprawling planning to achieve sustainable city.

The methodology applied in this study provides precious insights for the city policymakers into land use planning based on the transportation system constraints paving the way towards sustainable city development. According to enriched knowledge from findings of this research, it is found that how a practical model can be constructed to identify and land-use limits as a function of link volumes as well as providing research opportunities and horizons for sustainable development of cities.

It is regrettable that the traffic zone is the smallest level where the data on socio-economic and land use are available. In this study region there exist no data at parcel level. Thus, the first restriction which stop us from continuing our study from macro to micro scale, is lack of data at small parcel. As to the second restriction, the horizontal year of Isfahan city urban planning is 2025, accordingly, the results assessment of this methodology does not exceed 2025.

This paper opens up a number of research directions. Firstly, the solution can be examined by multiple data sets from other cities with various land use configurations and transportation network scales and complexity as well as applying other modeling techniques such as integrated land use planning and transportation models. Secondly, other prospective modeling scenarios that employ diverse policies for land-use and transportation providing a basis for enlightened decision to be made about future growth policies especially for cities like Isfahan with expected future population and spatial growth should be proposed and appraised. For instance, Future research such as modeling air pollutant emission concentration and vehicle emission distribution be beneficial to further study linkages between land-use limits, transportation system constraints and air quality and identify important factors leading to improved air quality of cities.

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References

Abdelwahab, H., & Abdel-Aty, M. (2002). Artificial neural networks and logit models for traffic safety analysis of toll plazas. *Transportation Research Record: Journal of the Transportation Research Board, 1784*, 115–125. https://doi.org/10.3141/1784-15.

Acheampong, R. A., & Silva, E. A. (2015). Land use–Transport interaction modeling: A review of the literature and future research directions. *Journal of Transport and Land Use, 8*(3), 11–38. https://doi.org/10.5198/jtlu.2015.806.

Aljoufie, M., Brussel, M., Zuidgeest, M., van Delden, H., & van Maarseveen, M. (2016). Integrated analysis of land-use and transport policy interventions. *Transportation Planning and Technology, 39*(4), 329–357. https://doi.org/10.1080/03081060.2016.1160578.

Bibri, S. E., & Krogstie, J. (2017). Smart sustainable cities of the future: An extensive interdisciplinary literature review. *Sustainable Cities and Society, 31*, 183–212. https://doi.org/10.1016/j.scs.2017.02.016.

Bigotte, J. F., Krass, D., Antunes, A. P., & Berman, O. (2010). Integrated modeling of urban hierarchy and transportation network planning. *Transportation Research Part A: Policy and Practice, 44*(7), 506–522. https://doi.org/10.1016/j.tra.2010.03.020.

Chang, J. S. (2006). Models of the relationship between transport and land-use: A review. *Transport Reviews: A Transnational Transdisciplinary Journal, 26*(3), 325–350. https://doi.org/10.1080/01441640500468432.

Cordera, R., Ibeas, Á., dell'Olio, L., & Alonso, B. (2018). *Land use–Transport interaction models.* CRC Press.

Deakin, E. A. (1991). Jobs, housing, and transportation: Theory and evidence on interactions between land use and transportation. *Transportation, Urban Form, and the Environment, Special Report, 231*, 25–42.

Dehnavi, H. K., Rezvan, M. T., Shirmohammadli, A., & Vallée, D. (2013). A solution for urban road selection and construction problem using simulation and goal programming—case study of the city of Isfahan. *Transport Policy, 29*, 46–53. https://doi.org/10.1016/j.tranpol.2013.04.003.

dell'Olio, L., Ibeas, A., & Cordera, R. (2016). *Project TRANSPACE - Advanced land use and transport interaction model (TRA2012-37659).* Ministry of Economy and Competitiveness (Goverment of Spain).

Dougherty, M. (1995). A review of neural networks applied to transport. *Transportation Research Part C: Emerging Technologies, 3*(4), 247–260. https://doi.org/10.1016/0968-090X(95)00009-8.

Dur, F., & Yigitcanlar, T. (2015). Assessing land-use and transport integration via a spatial composite indexing model. *International Journal of Environmental Science and Technology, 12*(3), 803–816. https://doi.org/10.1007/s13762-013-0476-9.

Emberger, G., Shepherd, S. P., & May, A. D. (2008). The effects of appraisal methodology on the specification of optimal urban transport strategies. *International Journal of Sustainable Transportation, 2*(1), 58–75. https://doi.org/10.1080/15568310701517067.

Friedrich, M., & Galster, M. (2009). Methods for generating connectors in transport planning models. *Transportation Research Record: Journal of the Transportation Research Board,* (2132), 133–142. https://doi.org/10.3141/2132-15.

Ghadirifaraz, B., Vaziri, M., Safa, A., & Barikrou, N. (2017). *A statistical appraisal of bus rapid transit based on passengers satisfaction and priority case study: Isfahan City, Iran (No. 17-05108)*.

Gong, Z. (1998). Estimating the urban OD matrix: A neural network approach. *European Journal of Operational Research, 106*(1), 108–115. https://doi.org/10.1016/S0377-2217(97)00162-8.

Hansen, W. G. (1959). How accessibility shapes land use. *Journal of the American Institute of Planners, 25*, 73–76. https://doi.org/10.1080/01944365908978307.

Iacono, M., Levinson, D., & El-Geneidy, A. (2008). Models of transportation and land use change: A guide to the territory. *Journal of Planning Literature, 22*(4), 323–340. https://doi.org/10.1177/0885412207314010.

IUT Technical Report (2008). *Updating Isfahan comprehensive study of transportation and traffic.* Isfahan University of Technology.

Jones, J. (2016). *Spatial bias in LUTI models* (Doctoral dissertation, Doctoral dissertation, Presse Universitaire de Louvain, Belgique).

Karlaftis, M. G., & Vlahogianni, E. I. (2011). Statistical methods versus neural networks in transportation research: Differences, similarities and some insights. *Transportation Research Part C: Emerging Technologies, 19*(3), 387–399. https://doi.org/10.1016/j.trc.2010.10.004.

Kikuchi, S., & Tanaka, M. (2000). Estimating an origin-destination table under repeated counts of in-out volumes at highway ramps: Use of artificial neural networks. *Transportation Research Record: Journal of the Transportation Research Board, 1739*, 59–66. https://doi.org/10.3141/1739-08.

Krüger, N. A. (2012). Estimating traffic demand risk–a multiscale analysis. *Transportation Research Part A: Policy and Practice, 46*(10), 1741–1751. https://doi.org/10.1016/j.tra.2012.07.002.

Lautso, K., Spiekermann, K., Wegener, M., Sheppard, I., Steadman, P., Martino, R., Domingo, A., & Gayda, S. (2004). *PROPOLIS: Planning and research of policies for land use and transport for increasing urban sustainability, Final report.* Project Funded by the European Commission.

Lorenzo, M., & Matteo, M. (2013). OD matrices network estimation from link counts by neural networks. *Journal of Transportation Systems Engineering and Information Technology, 13*(4), 84–92. https://doi.org/10.1016/S1570-6672(13)60117-8.

Middlesex Somerset Mercer Regional Council (1988). *The impact of various land use strategies on suburban mobility.* Retrieved 24 September 2006 fromPrinceton, NJ: Author. http://ntl.bts.gov/DOCS/470.html.

Miller, J. S., & Demetsky, M. J. (1999). Reversing direction of transportation planning process. *Journal of Transportation Engineering, 125*(3), 231–237.

Mussone, L., Grant-Muller, S., & Haibo, C. (2010). A Neural Network approach to motorway OD matrix estimation from loop counts. *Journal of Transportation Systems Engineering and Information Technology, 10*(1), 88–98. https://doi.org/10.1016/S1570-6672(09)60026-X.

Naphade, M., Banavar, G., Harrison, C., Paraszczak, J., & Morris, R. (2011). Smarter cities and their innovation challenges. *Computer, 6*, 32–39. https://doi.org/10.1109/MC.2011.187.

Nijkamp, P., Borzacchiello, M. T., Ciuffo, B., & Torrieri, F. (2007). Sustainable urban land use and transportation planning: A cognitive decision support system for the Naples Metropolitan Area. *International Journal of Sustainable Transportation, 1*(2), 91–114. https://doi.org/10.1080/15568310601091981.

Pérez, J. C., Carrillo, M. H., & Montoya-Torres, J. R. (2015). Multi-criteria approaches for urban passenger transport systems: A literature review. *Annals of Operations Research, 226*(1), 69–87. https://doi.org/10.1007/s10479-014-1681-8.

Pham, D. T., & Liu, X. (1995). *Neural networks for identification, prediction and control*.

Rodrigue, J. P. (1997). Parallel modelling and Neural Networks: An overview for transportation/land use systems. *Transportation Research Part C: Emerging Technologies, 5*(5), 259–271. https://doi.org/10.1016/S0968-090X(97)00014-4.

Sadek, A., & Mark, C. (2003). Modular artificial neural networks for solving the inverse transportation planning problem. *Transportation Research Record: Journal of the Transportation Research Board, 1836*, 37–44. https://doi.org/10.3141/1836-06.

Salavati, A., Haghshenas, H., Ghadirifaraz, B., Laghaei, J., & Eftekhari, G. (2016). Applying AHP and clustering approaches for public transportation decisionmaking: A case study of Isfahan City. *Journal of Public Transportation, 19*(4), 3. https://doi.org/10.5038/2375-0901.19.4.3.

Sheffi, Y. (1985). *Urban transportation networks.* London: Prentice-Hall International, Inc.

Simmonds, D., Waddell, P., & Wegener, M. (2013). Equilibrium versus dynamics in urban modelling. *Environment and Planning B: Planning and Design, 40*(6), 1051–1070 https://doi.org/10.1068%2Fb38208.

Szeto, W. Y., Jiang, Y., Wang, D. Z. W., & Sumalee, A. (2015). A sustainable road network design problem with land use transportation interaction over time. *Networks and Spatial Economics, 15*(3), 791–822. https://doi.org/10.1007/s11067-013-9191-9.

Thinh, N. X., Arlt, G., Heber, B., Hennersdorf, J., & Lehmann, I. (2002). Evaluation of urban land-use structures with a view to sustainable development. *Environmental Impact Assessment Review, 22*(5), 475–492. https://doi.org/10.1016/S0195-9255(02)00023-9.

Timmermans, H. (2003). The saga of integrated land use-transport modeling: How many more dreams before we wake up. In keynote paper, moving through nets: The physical and social dimension of travel. *10th International Conference on Travel Behavior Research*.

Vialard, A., & Carpenter, A. (2015). *Building density of parcels and block-faces from a syntactical, morphological and planning perspective. Proceedings of the 10th International Space Syntax Symposium* p. 100.

Waddell, P., Ulfarsson, G. F., Franklin, J. P., & Lobb, J. (2007). Incorporating land use in metropolitan transportation planning. *Transportation Research Part A: Policy and Practice, 41*(5), 382–410. https://doi.org/10.1016/j.tra.2006.09.008.

Wegener, M., et al. (2004). Overview of Land use transport models. In D. A. Hensher, K. J. Button, & K. E. Haynes (Eds.). *Handbook of transport geography and spatial systems*. Amsterdam: Elsevier.

Wegener, M. (2011). From macro to micro—how much micro is too much? *Transport Reviews, 31*(2), 161–177. https://doi.org/10.1080/01441647.2010.532883.

Wegener, M. (2014). Land-use transport interaction models. In M. Fischer, & P. Nijkamp (Eds.). *Handbook of regional science*Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-23430-9_41.

Wegener, M., & Fürst, F. (2004). *Land-use transport interaction: State of the art*.

WisDOT (1996). *Indirect and cumulative effects analysis for project induced land development. Technical reference guidance document.* Wisconsin Department of Transportation.

Yang, Y., Ng, S. T., Xu, F. J., & Skitmore, M. (2018). Towards sustainable and resilient high density cities through better integration of infrastructure networks. *Sustainable Cities and Society, 42*, 407–422. https://doi.org/10.1016/j.scs.2018.07.013.

Ye, M., Osman, O. A., Ishak, S., & Hashemi, B. (2017). *An ANN model for detecting secondary tasks from driving behavior attributes: A naturalistic driving study (No. 17-05057).* .

Zhou, Y., Huang, X., Chen, Y., Zhong, T., Xu, G., He, J., Xu, Y., & Meng, H. (2017). The effect of land use planning (2006–2020) on construction land growth in China. *Cities, 68*, 37–47. https://doi.org/10.1016/j.cities.2017.04.014.

Zhu, Z., Li, Z., Liu, Y., Chen, H., & Zeng, J. (2017). The impact of urban characteristics and residents' income on commuting in China. *Transportation Research Part D: Transport and Environment, 57*, 474–483. https://doi.org/10.1016/j.trd.2017.09.015.