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GIS-based analysis of relationship between building density and capacity of urban streets

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Abstract

Governments adopted the policy of increasing accumulation in cities in order to maximum use of desired lands of city districts and to prevent from city buildings in the environment created subsequent to the horizontal city developments. One of the basic foundations that must be evaluated while the population accumulation of capability increase, is the traction ability of accountability communication network in both public and private transport system to new travels created by any new user introduction. In this paper, we discussed about the relation between accumulation and traffic capacity of city streets with regard to a case study of Imam Khomeini Street in Tabriz city, Iran. This relation has been modeled with Logistic and AHP models. After investigating the service level of the street for 14 consecutive hours it is evident that the traffic is saturated at the peak hours and based on this study the suggestion for density increase is eliminated. Because the density increase is possible when v/c<1 at peak hours while this amount is higher than1 at (11-12) and (18- 19), Thus in order to improve the situation options like the travel building of the usages, the effect of BRT and street parking spaces were addressed.

1. Introduction

The unusual rapid growth of population in major cities, and consequently the need for housing in one hand and on the one hand large metropolitan problems has caused the experts to offer solutions (Kim & Kim, 2009). The governments have used the increase in density policy in order to optimal use of the desires lands, preventing the negative effect of city building in environment and horizontal extension of the cities. However, the examination before making policies is very important. One of the basic foundations that must be evaluated while the population of capability increase, is the traction ability of accountability communication network in both public and private transport system to new travels (Bhuyan & Nayak, 2013).

Due to vertical urban development policy for optimal use of the city potentials this study through studying the Tabriz Imam Street tries to examine the building density on the network through GIS modeling (Dahal & Chow, 2014).

2. Theoretical framework

2.1 Density

One of the main problems that the city residents are face is the density. Density as a measure has wide special place in decision-making and urban planning. Densities are classifying into 2 groups based on their type and kind:

1. Population density based on a man in hectare.
2. Building density based on the percentage.

Usually, the densities are classified in wide ranges. For example, the population density means population per area unit which is characterized by single man per hectare. The overall residential density is obtained through the ratio of the population of the city on the built areas. The built surface includes all the applications usages in the city, from residential to recreational or others (Jiang & Yao, 2006).

2.2. Traffic volume and road capacity

Traffic volume includes the number of vehicles that move across a road during a certain period of time (which is not necessarily defined), in a particular direction or directions of one or more lines of a road (Klosterman et al., 1993). Traffic volume might be defined for a special type of vehicle (such as cars, buses or trucks) or generally for all types of vehicles that move across a certain road and in this second situation the traffic volume unit is Passenger Car Unit or (PUC) based on table 1.

Table 1. Coefficient of vehicles on the road

Column	Vehicle	Urban roads		Rural roads
		Two line	Four line	
1	Car- taxi	1	1	1
2	Pickup- truck	1.2	1.3	1.1
3	Minibus	2.5	1.5	1.2
4	Bus	2.75	2.5	2
5	truck	5	4	3
6	Trailer	8	5	4
7	Motorcycles	0.5	0.7	0.5

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Road capacity is equivalent to maximum uniform passenger vehicles that can pass a point or section of a lane or pass through the whole way in a specific time and governing conditions of traffic.

2.3. The quality of traffic (service level)

The service level is a qualitative criterion indicating the traffic operation and the understanding of the passengers and the drivers of it. In traffic level a road has the two parameters of travel speed and the ratio of existing traffic volume on the highway capacity which is measurable (Landis et al., 1999). Generally, there are 6 types of services for different facilities. These levels are divided into levels A-F in which the level A indicate the best operation and the level F is the worst of them (Papinski & Scott, 2011).

3. The case study area

Tabriz is the greatest North-western metropolitan city of Iran which is about 131 km^2. The area under study is Emam Khomeini Street which one of the main axes of communication located in the north of district 2 and most of the area is under business or administrative application. After Janbazan square which is a traffic nod due to the extension of the business sites we face a special change into non-accumulated area. In addition to these nodes, the intersection of the Abresan and Shahryar Square are other nodes of this path (Lantada et al., 2009).

Figure 1. The land use of the area

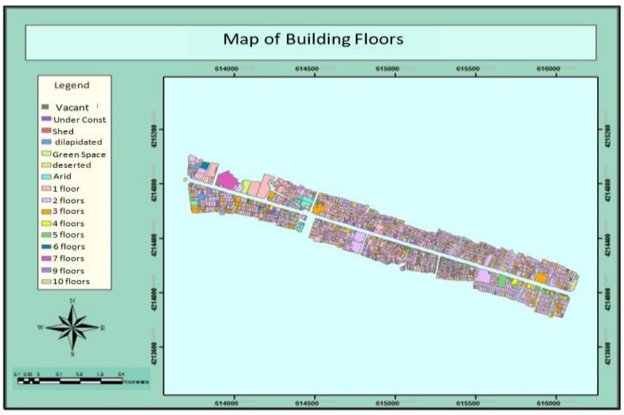


Figure 2. The buildings of the area

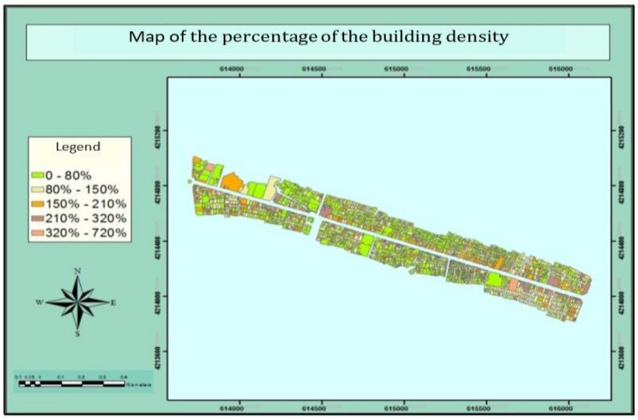


Figure 3. The percentage of the building density

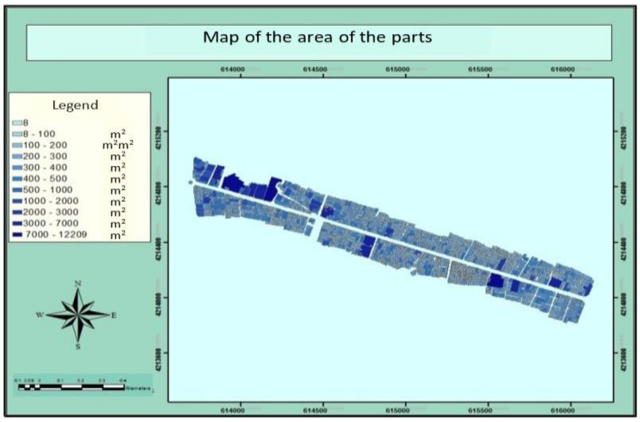


Figure 4. The area of the parts

4. The required data

The required data for this study are as follows:

1. The land use, building density and the street maps that can be obtained from the municipalities of the districts under study.

2. Raw Statistically measured and limited traffic data.

These figures have been collected in July 2nd in 2013 from West Point (opposite of the Museum of Azerbaijan) field and manually in 14 consecutive hours between the hours of 6am and 20pm.

These data include traffic information, including the number of passing vehicles from both sides of the Street divided into cars, vans and pickups, trucks, minibuses, buses, bicycles and motorcycles in the southern part of the street.

3. The statistical data about trip generations of uses.

These statistics are gathered at the peak of traffic hours to estimate the trip generation of the uses and ere gathered through field study and questionnaires.

5. Methods

5.1. Methods to measure and calculate the traffic volume (v)

Traffic volume may be measured through simple (manual calculation) or automatic counting system. In this research the manual method is used. The manual measurement is done through directly counting all the vehicles that pass a specific point. This is usually done with paper and pencil and drawing short lines clusters of five lines and … so that each line represents the passage of one vehicle. Then the accumulated statistics change into traffic volume through PCU equivalent conversion coefficients (Munoz,2003).

5.2. Methods to measure and calculate the practical capacity (c)

The capacity is equivalent to maximum uniform passenger vehicles that can pass a point or section of a lane or pass through the whole way in a specific time and governing conditions of traffic (table 2-7). Practical capacity, is the capacity that is lower than the ideal capacity in the saturation conditions. Practical capacity is achieved through the following equation 1.

$$C = 1800 \times g/c \times K1 \times K2 \times K3 \times K4 \times K5 \times K6 \quad (1)$$

Where:
C = capacity of the street
g = the effective green traffic lights
c = lights' cycle (total time of green, red, yellow).

Table 2. K1 = coefficient of capacity adjustment of left turn moves based on the opposite volumes

Number of main lines	coefficient of capacity adjustment for the opposite volumes				
	0-199	200-559	600-779	800-1000	1000+
Line 1	91%	50%	33%	25%	20%
Line 2	95%	75%	66%	62%	60%
Line 3	96%	83%	77%	75%	73%

Table 3. K2=the coefficient of setting the passengers down

Number of main lines	coefficient of capacity adjustment for the opposite volumes			
	high	medium	low	No parking
Line 1	61%	70%	80%	1
Line 2	80%	75%	90%	1
Line 3	85%	90%	95%	1

Table 4. K3 = coefficient of street parking

Number of main lines	coefficient of capacity adjustment for the opposite volumes			
	high	medium	low	No parking
Line 1	20%	69%	80%	1
Line 2	50%	70%	85%	1
Line 3	50%	75%	90%	1

Table 5. K4=coefficient of adjustment within each lane

Line width	2.50	2.75	3	3.25	3.5	3.75
coefficient of adjustment	87 %	90 %	93%	97%	99%	1

Table 6. K4=coefficient of adjustment within each lane

Number of lines	One line	More than 1 line
coefficient of adjustment	90%	95%

Table 7. K5=coefficient of adjustment to the streets without refuge lane

Type of district	coefficient of adjustment
central	90%
other	1

5.3. Method of determining the quality of traffic flow (service level=v/c)

To evaluate the quality of network e usually six conditions are considered. Table 8 indicated the quality of traffic flow in different methods and the quality of each one of them. In order to determine the traffic, flow the ratio of actual volume on practical capacity is used (V/C).

Table 8. Determining the level of service based on the traffic volume on the street capacity or speed

Descriptions	The mean of velocity	v/c	Traffic quality
Excellent quality	55	≤ 0.35	A
High Quality	45	0.35 – 0.50	B
Good quality	35	0.50 – 0.75	C
Minimum acceptable quality	27	0.75 – 0.90	D
Quality in a state of absolute capacity (inappropriate)	20	0.90 – 1	E
very poor quality (unstable and traffic jams)	16	> 1	F

6. Results and findings

In this stage based on the above-mentioned methods the traffic volume, road capacity, the quality of traffic flow and the amount of trip generation of the usages are analyzed and then the impact of density factor on the road traffic is discussed.

6.1. Traffic volume

Table 9 represents the statistics on traffic volume of the district under study in 14 consecutive hours in a regular day. The data were collected for all the hours of the study according to the following table example (for 12 o'clock.

Table 9. Determining the level of service based on the traffic volume on the street capacity or speed

History June 2nd 2013	Towards the Abresan intersection								Position (opposite the Museum of Azerbaijan)	
Time/ Vehicle Type	Car	Van and Pickup	Bus	Minibus	Truck	Truck	Bicycle	Motorcycle	Total	%
12-12:15	359	22	0	0	0	4	10	22	417	23.84219554
12:15-12:30	361	18	0	0	0	0	8	22	409	23.38479131
12:30-12:45	346	26	0	0	0	1	7	23	403	23.04173814
12:45-13	451	23	0	0	1	3	15	27	520	29.73127501
Total	1517	89	0	0	1	8	40	94	1749	100
Equivalent	1	1.2	2.75	2.5	3	2	0.3	0.5	13.25	0
Volume	1517	106.8	0	0	3	16	12	47	1701.8	0

Table 10. Street traffic from 6 to 20

Traffic Volume	Hour	Traffic Volume	Hour
455.1	6_7	1755.6	13_14
1130.8	7_8	1402.8	14_15
1154.8	8_9	1381.8	15_16
1428.8	9_10	1435.3	16_17
1663.6	10_11	1754.6	17_18
1893	11_12	1935.2	18_19
1701.8	12_13	1672.95	19_20

6.2. Practical capacity

Using section, the method in 4-3 the practical capacity of the streets is calculated for each hour. The response to the calculations is presented in table 11. The Method of calculation is given in the following table.

Table 11. The practical capacity of the street during the hours of 8 to 14 and 16 to 19 per an hour

Calculating the capacity of the streets at all hours		n.L	3
Fixed adjustment coefficient		1800	
Capacity adjustment coefficient of the left turn movements based on the opposite volumes		K1	73%
Street Parking coefficient		K2	50%
Lane width adjustment coefficient for each lane		K3	99%
adjustment coefficient for the streets without refuge		K4	100%
The adjustment coefficient to set out the passengers		K5	90%
adjustment coefficient of urban areas		K6	100%
g/c = 1	Green light Time	g	
	Traffic lights (all lights green, yellow, red)	c	
1756.161		C	

Table 12. Passage Capacity between 6 – 20

Hour	C
6_7	3414.5
7_8	3336.7
8_9	1756.2
9_10	1756.2
10_11	1756.2
11_12	1756.2
12_13	1756.2
13_14	1756.2
14_15	1756.2
15_16	2634.2
16_17	1756.2
17_18	1756.2
18_19	1756.2
19_20	1756.2

6.3. The service level of the road

After performing the stages, the service level is determined as follows (Table 13):

Table 13. The service level of the road from 6 to 20 o'clock

Service Level	V/C	Hour
A	0.133285	6_7
A	0.338898	7_8
C	0.657556	8_9
D	0.813575	9_10
E	0.947273	10_11
F	1.077895	11_12
E	0.969024	12_13
E	0.999658	13_14
D	0.79877	14_15
C	0.524562	15_16
D	0.817276	16_17
E	0.999089	17_18
F	1.101925	18_19
E	0.952597	19_20

The maximum acceptable value for v / c for the proposed density is 0.9 (Neckerman et al., 2013). As it is clear from the table above the service level of the street in the noon peak hours (11-12) and afternoon (18-19) is in level F (very poor quality (unstable and traffic jams) and v/c>1. So, it can be concluded that the street capacity is saturated at the peak hours. So, in order to improve the street service level, the effective factors (travel building of the uses, BRT and street parking) on traffics are examined and some recommendations are provided.

The usages are divided into 6 main classes of Residential, Business, Administrative, Educational, religious-cultural and Treatment usage. The impact of each usage is analyzed as follows: Due to the summer vacation the school areas are not included in educational usage. According to table 14 the largest area which is 443200 m^2 belongs to residential usage and the most travels (3102.4) belong to this category and after that the business usage has the highest travel making rate.

Table 14. The usages' trip generation.

Usage	Total usage area	Usage trip generation per 100 meters (n)	Total trip generation of the usage
Residential	443200	0.7	3102
Business	134413	1.25	1680
Educational	6311	12	757
Religious-cultural	7683	10	768
Treatment	8442	6	506
Administrative	38333	1.4	545
Total of all applications	649291	-	8867.6175

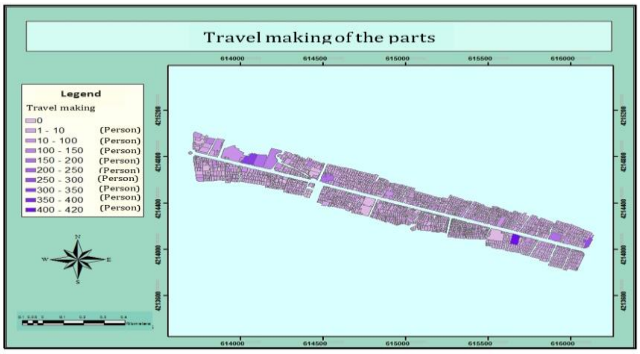


Figure 5. Trip generation of the parts

The trip generation of each usage for each travel and the effect of the usages on the service level are determined.

Table 15. The trip generation of each usage for each travel

Usage	car	taxi	bus	Pedestrian and bicycle
Residential	42%	18%	17%	23%
Business	31%	28%	24%	17%
Educational	7%	14%	52%	27%
Religious-cultural	12%	16%	46%	26%
Treatment	32%	21%	34%	13%
Administrative	23%	12%	38%	27%

According to the table 15 the residential, business and treatment usages possess the highest percentage of cars and taxi use thus they have the highest effect on street service level.

According to the methods mentioned in part 4 the number of generated trips to the vehicles is estimated. And the street service level is calculated in the absence of that usage and eventually the traffic is determined (table 16).

Table 16. the number of cars for each usage

Usage	Car	Taxi	Total
Residential	655	187	842
Business	260	156	416
Educational	26	35	61
Religious-cultural	46	40	86
Treatment	80	35	115
Administrative	21	60	81
Total	1088	513	1601

The service level of the street in the absence of the usages is as follows:

Table 17. The service level of the street in the absence of the usages

Usage	C	Service level	C in the absence of usage	The service level of the street in the absence of the usages
Residential	1.1	F	0.62	C
Business	1.1	F	0.86	D
Educational	1.1	F	1.06	F
Religious-cultural	1.1	F	1.05	F
Treatment	1.1	F	0.97	E
Administrative	1.1	F	1.05	F
Total	1.1	F	0.19	A

7. Modeling

The modeling method of this study is the logistic model, MEC and FUZZY - AHP of Idrisi software and Fuzzy(membership) in Arc GIS 10.1.

The required levels of this model to analyze the effect of usage on the street include the passage layer and the separate usage layers (Li, 2007). The usages are divided into 6 main classes of Residential, Business, Administrative, Educational, religious-cultural and Treatment usage. Each usage is classified into 5 classed based on the density and travel making in Arc GIS 10.1 software and through the analytical functions the maps are changed into images and transferred into Idrisi software for image modeling. Then in order to perform the logistic modeling through the data entry option and edit and assign orders the classes for each layer are weighted. According to the findings of traffic study studies 3 important effective usages (residential, business and treatment) are identified and analyzed in street service level trough the logistic model. In order to perform the model, the GIS analysis option, Statistics function and LOGISTICREG order are used.

Then in order to perform the MES model the GIS analysis option, Statistics function and LOGISTICREG order are used. Also, in order to perform the AHP-Fuzzy the WEIGHT and Decision Wizard were used.

Then the ROC test was performed. If the answer of the test is above 0.9 it means that the model is correct.

7.1. Logistic model

The street under study is the dependent variable and the three identified usages that affect the street traffic are the independent variables.

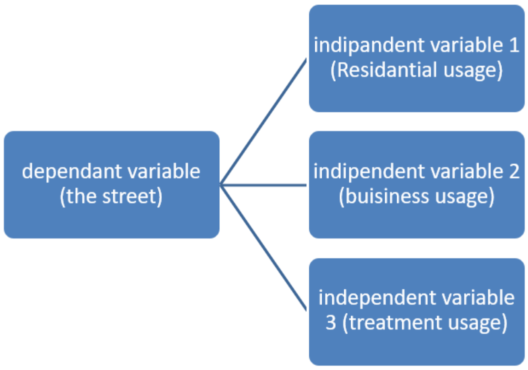


Figure 6. Logistic model

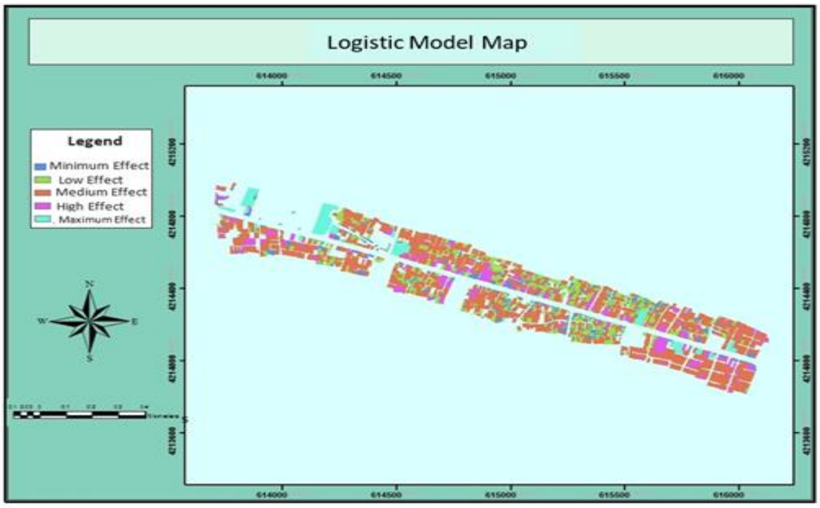
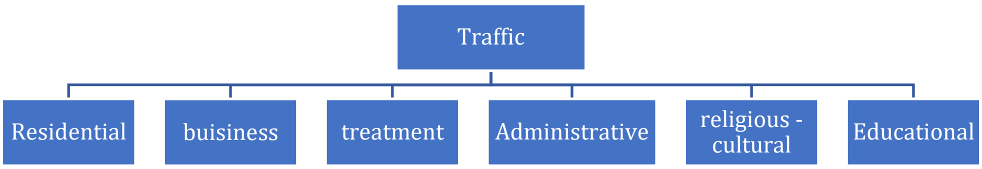


Figure 7. The service level of the street in the absence of the usages

7.2. AHP model

In the AHP model the criteria based on the purpose and the sub criteria based on the criteria are classified into pairs and compared in a matrix and are ranked 1-9 based on their impact factor. And eventually the final factor of the sub criteria is calculated. The calculations are linear without considering the dependence among the criteria and sub criteria (Pan et al. ,2013).

In this method the impact factor of all 6 usages is determined. First the weighting criteria of table 9 a time variable is calculated as a 9*9 matrix.



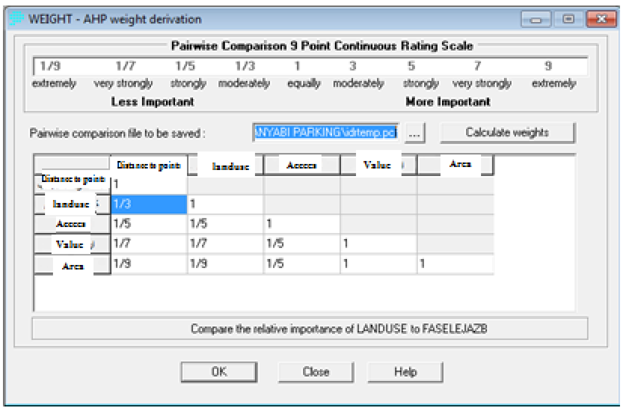


Figure 8. The weight of each usage is as follow

Table 18. The results of weighting

Residential	Business	Treatment	Administrative	Religious- cultural	Educational
0.4779	0.2365	0.1375	0.0593	0.0593	0.0295

Also, each usage factor is classifying into 5 classes based on the trip generation and each class is weighted. The CR of this model is 0.03 which is acceptable. The Idrisi software does not represent a map for AHP.

8. Conclusion

System of Traffic Planning and Urban Design in order to select urban land, their densities, locating them in different areas of development or particular users, needs to be aware of trip generation characteristics of each user is the traffic impact assessment, so that the usage replacement or any other measure would be based on the impacts imposed on the networks that lead to the structure. After investigating the service level of the street for 14 consecutive hours it is evident that the traffic is saturated at the peak hours and based on this study the suggestion for density increase is eliminated. Because the density increase is possible when v/c<1 at peak hours while this amount is higher than1 at (11-12) and (18- 19), Thus in order to improve the situation options like the travel building of the usages, the effect of BRT and street parking spaces were addressed.

References

Bhuyan, P., & Nayak, M. S. (2013). A review on level of service analysis of urban streets. *Transport Reviews,* 33, 219-238. https://doi.org/10.1080/01441647.2013.779617

Dahal, K. R., & Chow, T. E. (2014). A GIS toolset for automated partitioning of urban lands. *Environmental Modelling & Software*, 55, 222-234. https://doi.org/10.1016/j.envsoft.2014.01.024

Jiang, B., & Yao, X. (2006). Location-based services and GIS in perspective. *Computers, Environment and Urban Systems,* 30, 712-725. https://doi.org/10.1016/j.compenvurbsys.2006.02.003

Kim, J. J., Kim, D. Y. (2009). Effects of a building's density on flow in urban areas. Advances in Atmospheric Sciences, 26, 45-56. https://doi.org/10.1007/s00376-009-0045-9.

Klosterman, R. E., Brail, R. K., & Bossard, E. G. (1993). *Spreadsheet models for urban and regional analysis*. Center for Urban Policy Research.

Landis, J., Zhang, M., & Fotheringham, A. (1999). Using GIS to improve urban activity and forecasting models: three examples. *Spatial models and GIS: New potential and new models*, 63-81.

Lantada, N., Pujades, L. G., & Barbat, A. H. (2009). Vulnerability index and capacity spectrum-based methods for urban seismic risk evaluation. A comparison. *Natural hazards*, 51, 501-524. https://doi.org/10.1007/s11069-007-9212-4

Li, D. F. (20079. Compromise ratio method for fuzzy multi-attribute group decision making. *Applied Soft Computing*, 7(3), 807-817. https://doi.org/10.1016/j.asoc.2006.02.003

Munoz, F. (2003). Lock living: urban sprawl in Mediterranean cities. *Cities*, 20, 381-385. https://doi.org/10.1016/j.cities.2003.08.003

Neckerman, K. M., Purciel-Hill, M., Quinn, J. W., Rundle, A. (2013). *Urban design qualities for New York City. In: measuring urban design. Metropolitan planning + design*. Island Press.

Pan, G., Qi, G., Wu, Z., Zhang, D., & Li, S. (2013). Land-use classification using taxi GPS traces. *Intelligent Transportation Systems, IEEE Transactions,* 14(1), 113-123. https://doi.org/10.1109/TITS.2012.2209201

Papinski, D., & Scott, D. M. (2011). A GIS-based toolkit for route choice analysis. *Journal of Transport Geography*, 19, 434-442. https://doi.org/10.1016/j.jtrangeo.2010.09.009