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A Decision Support System (FMOTS) for Location Decision of Taxicab Stands

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1. Introduction

Taxi systems and their municipal organization are generally problem area in the metropolitan cities of developing countries. The locations of taxicab stands can be market-oriented and can cause chaos. A decision support system is needed for the related agencies to solve such kind of problems. In this chapter, a decision support system for taxicab stands that can be used in any metropolitan area or municipality is presented. The study attempts to create a scientific basis for decision makers to evaluate the location choices of taxicab stands in major cities with the help of GIS and fuzzy logic.

Taxi, which has been worldwide used since the 19th century, is an indispensable component of urban transport. Compared to other modes of transport, taxi has a relative advantage with the comfort and convenience that it provides 24 hours a day to its users. However, it is criticized because of its low occupancy rates and traffic burden it loads on urban streets.

Taxicab stands offer a viable service by providing an identifiable, orderly, efficient, and quick means to secure a taxi that benefits both drivers and passengers (Giuliani et.al, 2001). Stands are normally located at high-traffic locations such as airports, hotel driveways, railway stations, subway stations, bus depots, shopping centers and major street intersections, where large number of passengers are likely to be found. The choice of location for taxicab stands depends only on legal permissions. From the legal authorities' side, there is no evidence of taking some scientific criteria into account while giving the permission. The entrepreneurs willing to manage a taxicab stand have limitless opportunities to select any point on urban land. These free market conditions cause debates on location choices of taxicab stands.

In some cities, taxi companies operate independently and in some other cities, the activity of taxi fleets is monitored and controlled by a central office, which provides dispatching, accounting, and human resources services to one or more taxi companies. In both systems, the optimum organization of taxi companies on urban space is a problem. The taxi company in the system should provide the best service to the customer, which includes reliability and minimum waiting time.

As private entrepreneurs, taxi companies tend to locate in some certain parts of the city, where they believe they can find more passengers. The decision makers, on the other hand, should find an optimum between taxi companies' demands and the city's real needs. They

would rather improve the effectiveness of taxicab stands as a tool to reduce congestion, while improving convenience for passengers and taxi drivers.

There are two major obstacles confronting the decision makers, who try to evaluate location choices of taxi companies: The first is about the scale of the analyzed area. Taxicab stands are the problem of major cities and managing data in this scale requires specific methods. In this study, GIS based service area analyses helped to define the area, which can be accessed from taxicab stands within a psychologically accepted time limit (and critical areas that are out of service range).

The second problem of the decision makers is the lack of a certain measure for this specific decision. An alternative way of thinking, which allows modeling complex systems using a higher level of abstraction originating from our knowledge and experience, is necessary. Fuzzy logic is an organized and mathematical method of handling inherently imprecise concepts. It has proven to be an excellent choice for many control system applications since it mimics human control logic. It uses an imprecise but very descriptive language to deal with input data more like a human operator.

This study appeared as a response to the demands of the municipalities and the taxi associations in Turkey. The research is focused on both issues: how well the existing taxicab stands are located and where the most appropriate places for the incoming demand should be. The pioneering steps of the study have already been presented in a scientific paper (Ocalir, et. al, 2010). An integrated model of GIS and fuzzy logic for taxicab stand location decision is built. GIS were used for generating some of the major inputs for the fuzzy logic model. The location decisions of taxicab stands in big cities, where organizational problems of taxicab stands slow down a better quality of service, have been examined by this integrated model and their appropriateness has also been evaluated according to the selected parameters. With the fuzzy logic application, evaluation of the existing taxicab stands is done and decision for new taxicab stands is given. The equations are obtained by artificial neural network (ANN) approach to predict the number of taxicab stands in each traffic zone.

In the next section, background information for the tools used (the integration of GIS and fuzzy logic) is provided. It is followed by the introduction of a decision support system, the Fuzzy Logic Model for Location Decisions of Taxicab Stands (FMOTS), with a case study in Konya (Turkey). The applicability of the FMOTS model for big cities for the selected case study Konya (Turkey) with a population of approximately 2000000 will be examined.

The taxicab stand allocating problem came in agenda as taxi use gained importance in recent years parallel to the development of university and its facilities. Having sprawled to a large area in a plain, Konya accommodates different sustainable transportation systems. FMOTS should be applied to this city for understanding supply and demand of taxicab stands. Advanced GIS techniques on networks, fuzzy logic 3D illustrations and artificial neural network equations for new demands will be given for taxicab stands in Konya, Turkey. The paper closes with conclusions.

2. Incorporating fuzzy logic into GIS operations

Defining service areas is an important geographical application (Upchurch et.al, 2004) and with use of GIS, some studies have been performed. The service area analysis of transit services by GIS has been performed in O'Neill (1995) and Horner and Murray (2004)'s researches. In O'Neill's (1995) study, by defining a transit route's service area, walking

distance and travel time were used as acceptable limits for transit users. Another study with GIS was performed (Walsh et al., 1997) for exploring a variety of healthcare scenarios, where changes in the supply, demand, and impedance parameters were examined within a spatial context. They used network analysis for modeling location/allocation to optimize travel time and integrated measures of supply, demand, and impedance.

Fuzzy systems, describe the relationship between the inputs and the output of a system using a set of fuzzy IF-THEN set theory (Zadeh, 1965). The classical theory of crisp sets can describe only the membership or non-membership of an item to a set. Fuzzy logic, on the other hand, is based on the theory of fuzzy sets, which relates to classes of objects with unsharp boundaries, in which membership is matter of degree. In this approach, the classical notion of binary membership in a set has been modified to include partial membership ranging between 0 and 1.

Fuzzy Logic will be increasingly important for GIS. Fuzzy Logic accounts a lot better to uncertainty and impreciseness in data as well as to vagueness in decisions and classifications than Boolean Algorithms do. Many implementations have proved to get better output data. In the recent years, fuzzy logic has been implemented successfully in various GIS processes (Steiner, 2001). The most important contributions are in the fields of classification, measurement, integrated with remote sensing (Rashed, 2008), raster GIS analysis and experimental scenarios of development (Liu and Phinn, 2003), risk mapping with GIS (Nobre et al., 2007; Ghayoumian, et.al,2007; Galderisi et.al, 2008), ecological modeling (Malins and Metternicht, 2006; Strobl, et.al, 2007), qualitative spatial query (Yao and Thill, 2006), data matching (Meng and Meng, 2007), site selection (Alesheikh et.al, 2008; Puente et al., 2007) and finally in road network applications (Petrik et al., 2003).

In the scientific literature, there are many studies, which implements fuzzy logic onto some transport problems. Some of these studies focus on transport networks. Choi and Chung (2002) for instance, developed an information fusion algorithm based on a voting technique, fuzzy regression, and Bayesian pooling technique for estimating dynamic link travel time in congested urban road networks. In another study (Chen et.al, 2008) used fuzzy logic techniques for determining the satisfaction degrees of routes on road networks. Ghatee and Hashemi (2009) studied on a traffic assignment model in which the travel costs of links depend on their congestion. Some other studies are on signalized junctions, which are closely related with queuing theory: Murat and Baskan (2006) developed a vehicle delay estimation model especially for the cases of over-saturation or non-uniform conditions at signalized junctions. Murat and Gedizlioglu (2005) developed a model for isolated signalized intersections that arranges phase green times (duration) and the other phase sequences using traffic volumes. In another study, Murat and Gedizlioglu (2007) examined the vehicle time headways of arriving traffic flows at signalized intersections under low traffic conditions, with data from signalized intersections.

The model brings some innovation by implementing fuzzy logic to a transport problem for an area based analysis. Point and linear analyses could not bring solutions to the mentioned problem. An area-based analysis on traffic zones is required to give transportation planning decisions about an urban area with respect to some land use data such as employment and population. An analytic process and fuzzy logic functions have been considered for the evaluation of model stages. The fuzzy logic permits a more gradual assessment of factors. The implementation of the whole model requires a big amount of information, so the model validation has been done only at the traffic zone level.

Increasing awareness about the need of designing and performing new development and site selection models has made necessary the implementation of many more new factors and

parameters than those presented in traditional location models, which results major complexity for the decision making processes. That is the reason why in this research a GIS platform has been used to spatially analyze the service area of taxicab stands, bearing in mind the hierarchical structure of location factors and considering the fuzzy logic attributes. The new proposed methodology gathers the necessary tools: GIS software, to organize the datasets and to apply geo-processing functions on a clear interface; Fuzzy Logic software, to define and execute the evaluation methodology and to carry out the evaluation process. The creation of an expert system based on GIS software allows the user to query the system using different groups of criteria. This makes the planning process for the decision makers easier.

The fuzzy logic gives the system a type of evaluation closer to the complex reality of urban planning. The FMOTS is a helpful tool based on a multi-criteria evaluation methodology. Location attributes are an important source of information for empirical studies in spatial sciences. Spatial data consist of one or few cross-sections of observations, for which the absolute location and/or relative positioning is explicitly taken into account on the basis of different measuring units. Using fuzzy logic operators for modeling spatial potentials brings more sophisticated results because the information about membership values gives a more differentiated spatial pattern. A lot of the events, which are analyzed using spatial analysis techniques, are not crisp in nature. To analyze such events, it is common to commute fuzzy data into crisp data, which stands for a loss of information (Wanek, 2003).

GIS operations for data interpretation can be viewed as library of maps with many layers. Each layer is partitioned into zones, where the zones are sets of locations with a common attribute value. Data interpretation operations available in GIS characterize locations within zones. The data to be processed by these operations include the zonal values associated with each location in many layers (Stefanakis et al., 1996). A new class of data with measurement operations in this field that correspond to the area and length characterizing the traffic zones is computed. The transformation of these values is accomplished through fuzzification. This study gives a methodology to quantify taxicab stand complexity using fuzzy. In essence fuzzy logic opens the door to computers that understand and react to the language and the behavior of human beings rather than machines (Narayanan et al., 2003).

3. System design

In this study, an expert system based on fuzzy logic with related modelling software and the GIS software is developed. The model permits us generate digital suitable locations and can also be used to evaluate existing taxicab stands from a sustainable point of view. It is indeed a decision support system, which is an integrated model of GIS and fuzzy logic applications. The design of the proposed model is given in Fig. 1. After the definition of the problem, GIS application begins. The tabular data, together with geo-referenced data, are processed by GIS applications. However, some outputs of this phase needs some further process with a fuzzy logic application. In this fuzzy logic application, in addition to some former tabular data, the amount of roads which have (AND don't have) adequate taxi service, are calculated by network analysis tool of GIS and used as basic inputs.

The location analysis of the taxicab stands in Konya begins with GIS. The first level of a GIS study is the database creation process, which is necessary for network analysis. Some points should be noticed before dealing with the networking database, such as the data structure, data source and the consistency of the database.

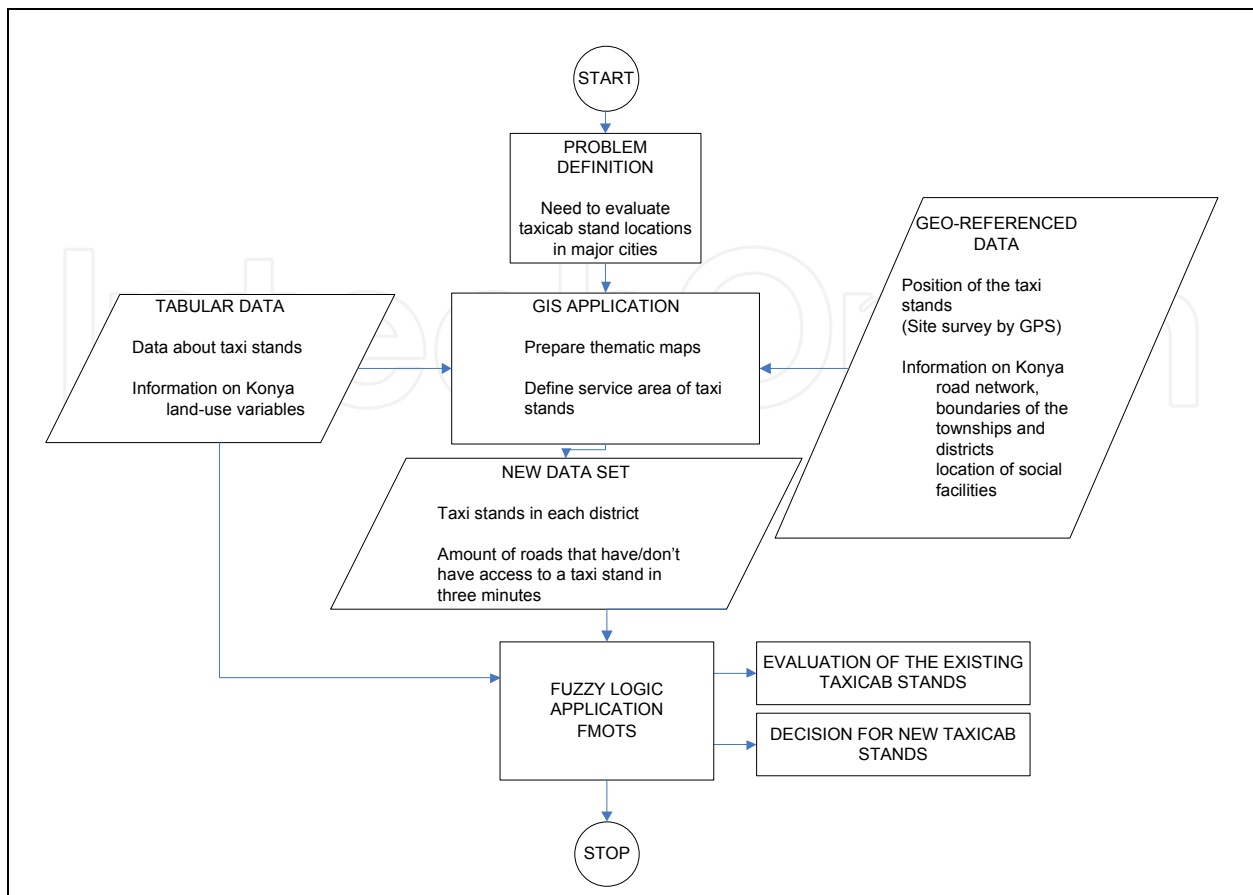


Fig. 1. The design of the decision support system

The geo-referenced data are grouped as spatial and descriptive data. Spatial data determine location, form and relationships with other features. The data of the location of taxicab stands all over Konya and the road network map have been received from a GIS software provider in Turkey (Basarsoft) as a contribution to our study. The spatial data collected for this study are: the current road network for the whole city, the district boundaries, locations of the social facilities and the locations of taxicab stands. Descriptive data are listed on the database. The database includes traffic directions and average speeds. Traffic zones are overlaid onto the road network. The data related to the traffic zones contains employment, area and population information and have been received from Konya Municipality for this study. These data are current names of the roads, the districts, population of the districts, traffic zones, car ownerships and the names and the addresses of taxicab stands.

Traffic zones are generally used as planning units for urban transportation planning processes. Many thematic maps were produced according to these geo-referenced data, such as population map, the number of taxis in the taxi stands with population, matched and unmatched taxicab stand locations. Some comparisons among the districts according to the number of taxicab stands are made. The GPS was calibrated in the most accurate way. All projections were set to UTM (Universal Transverse Mercator) and WGS84 reference systems, zone 36 referring to Konya. No overlaying and accuracy problems appeared for overlaying operations with the same projection and reference system in the metropolitan scale.

The other data about road network include directions as two-ways and one-way and speed limits. The data were compiled in GIS environment together with population, district

boundaries and urban social facilities. These data were used as the criteria for the site selection of taxicab stands. The results were matched with the spatial data and overlaid with districts.

The accessibility and service area analyses were produced by network analysis tool of GIS. The road network of Konya, including all updated directions, district borders and the location of taxicab stands are overlaid as thematic maps. A psychological threshold of 3 minutes is accepted for taxi users to have access to any taxi. Service area analysis of 53 taxicab stands was performed for each of the stands in 3 minutes drive time according to the road network map. With the help of an additional network analysis tool, travel time was specified in a problem definition dialog. The defined service area and the network according to the given travel time (3 minutes) were displayed as cosmetic layers in the view. These cosmetic layers were added onto one by one and then they were turned to a thematic layer as 3 minute network from the location of taxicab stands (Fig. 2). A geodatabase was built showing the lengths of roads within and outside the service area. The obtained data were used as inputs of a fuzzy logic application.

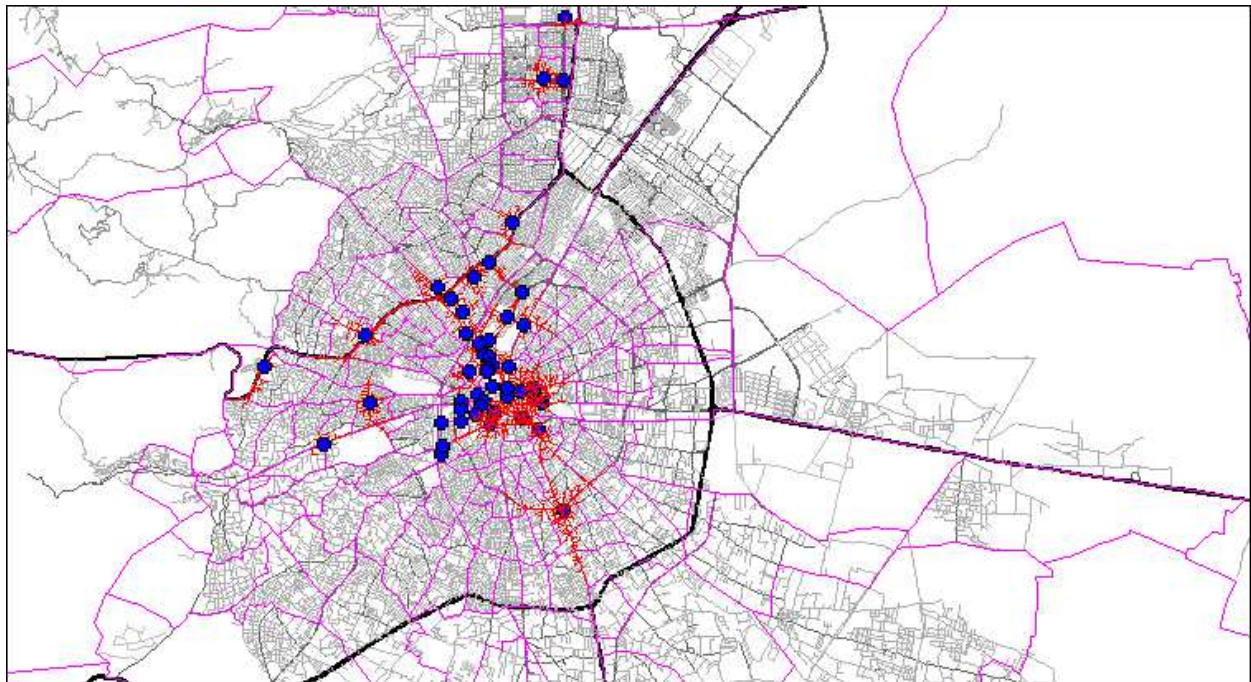


Fig. 2. The road network and three minutes psychological threshold (in red) for the accessibility of existing taxicab stands

With the fuzzy logic application, evaluation of the existing taxicab stands is done and decision for new taxicab stands is given. The equations are obtained by artificial neural network (ANN) approach to predict the number of taxicab stands in each traffic zone.

4. Background information on Konya

The area of interest is Konya, a big to medium size city in Turkey. The population of Konya by the year 2008 is 1969868 (TUIK, 2008). There are 434000 vehicles of which 185000 are cars by the year 2009 (TUIK, 2009). Total road network is 1060 km and 53 taxicab stands are determined in the field study. Land-use data are obtained from the Konya Municipality and

the company Basarsoft for the year 2009. Although there are 213 districts in Konya, 99 of them, which are close to the central areas, are included in the FMOTS model.

City centre is composed of two adjacent parts, the traditional and the modern centres. The development is in industrial areas located in the northern and the north eastern parts of the city. The dense settlements are in the north western parts of Konya. Population in these districts are expected to increase in the following years. In the northern part of the city, an important university campus is located. The southern, the south-eastern and the eastern parts of the city are lower-density settlements .

Bicycle is an important mode of travel in Konya. The flat structure of the city supports bicycle networks. However, developments in the recent years have brought a more intensive use of motorised vehicles.

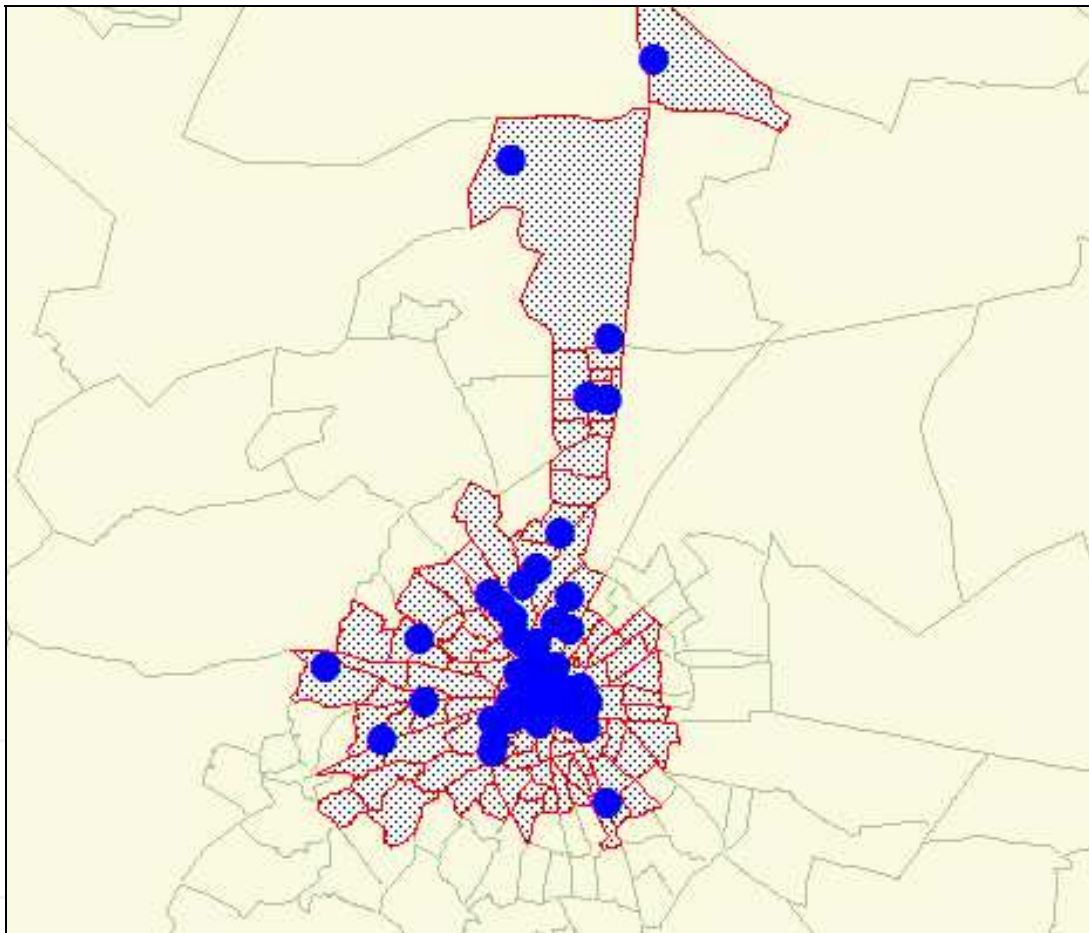


Fig. 3. The selected urban districts (esp. city center) which are included in the study and the locations of existing taxicab stands

There are no restricted conditions about site selection of taxicab stands in Konya. A fuzzy model is developed to build up a decision support system for decision makers.

5. The Fuzzy Model of Taxicab Stands (FMOTS)

For the FMOTS operation, 5 parameters, which may influence the optimum number of taxicab stands, have been defined (Fig.4). The first two of them, employment density

(Emp/km²) and population density (Pop/km²), are related with the urban morphology and describe the patterns of land use. The third parameter is the car ownership level (PCP), which is accepted as an indicator of the income level. The fourth and fifth parameters (ROSA and RWSA), the amounts of roads within and out of taxicab stands' catchment area, which are limited to 3 minutes as a psychological threshold, are the supply and the potential of taxi service respectively. The last two parameters have been determined by GIS. The proposed model is suggested to be a useful support tool for decision makers for defining the optimum number of taxicab stands especially in the newly developed regions and zones. It is assumed that each taxicab stand is available to supply necessary number of taxis when needed.

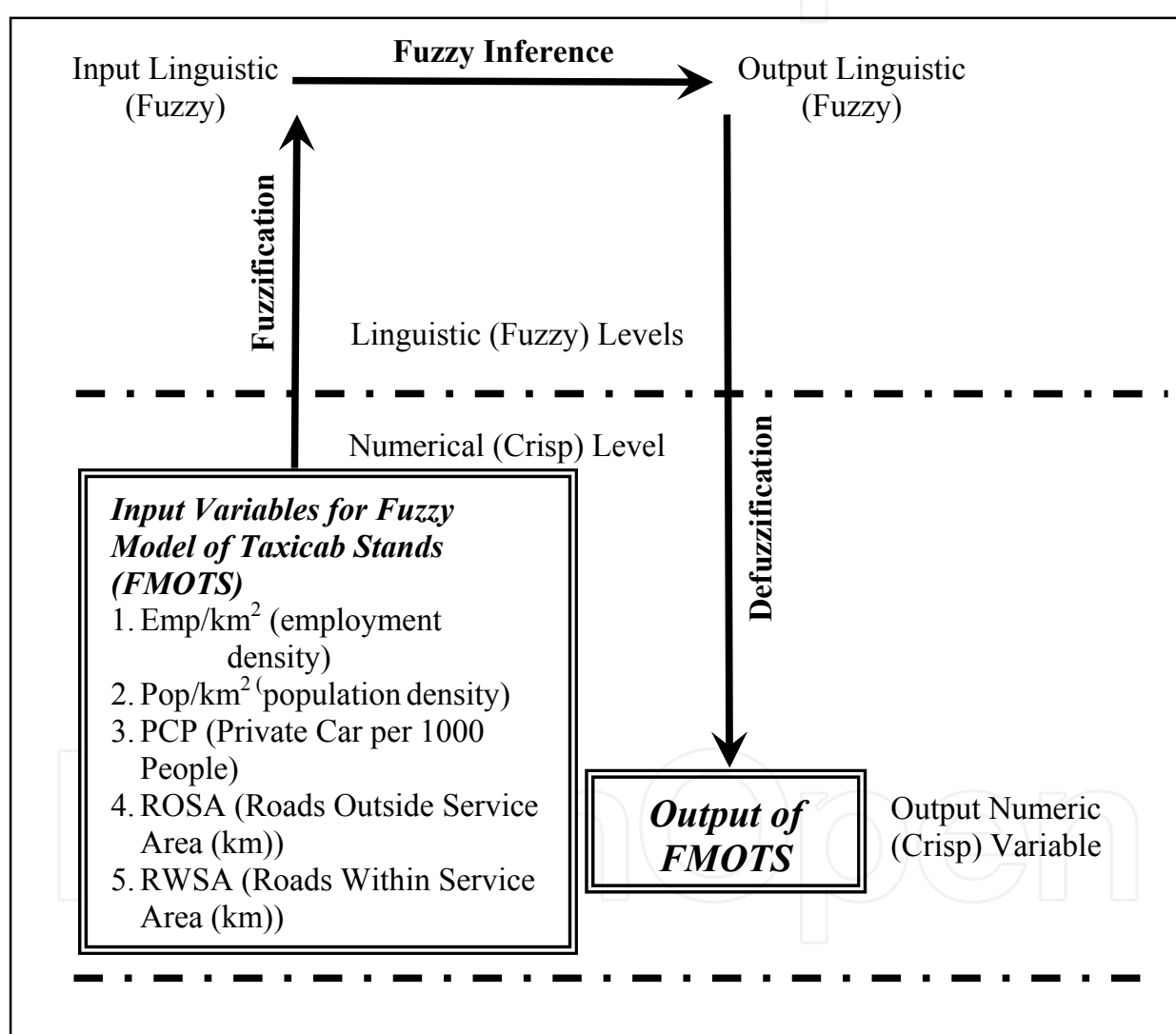


Fig. 4. Prototype FMOTS Model

Triangular membership functions have been used extensively in different applications because of their simplicity. A triangular membership function can be defined by a triplet (ϕ_1, ϕ_2, ϕ_3) , as shown in Fig 5. The membership function for a triangular membership function is defined as:

$$\mu(x) = \begin{cases} 0, & x < \phi_1 \\ \frac{(x - \phi_1)}{(\phi_2 - \phi_1)} & \phi_1 \leq x \leq \phi_2 \\ \frac{(\phi_3 - x)}{(\phi_3 - \phi_2)} & \phi_2 \leq x \leq \phi_3 \\ 0, & x > \phi_3 \end{cases}$$

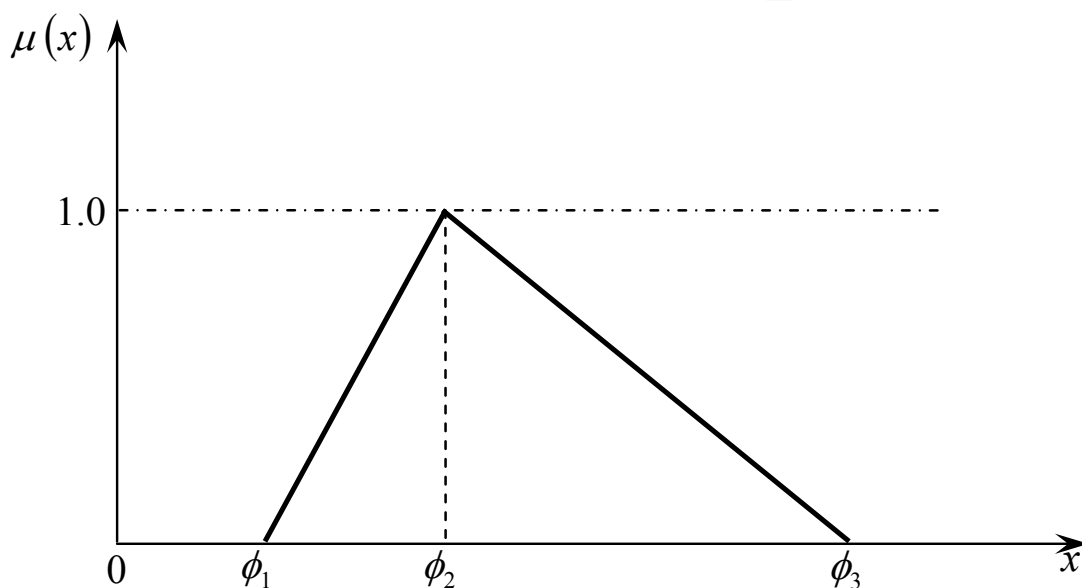
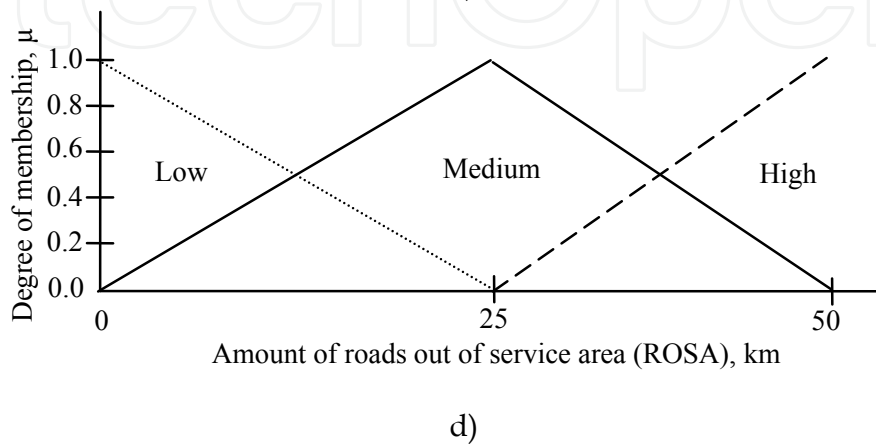
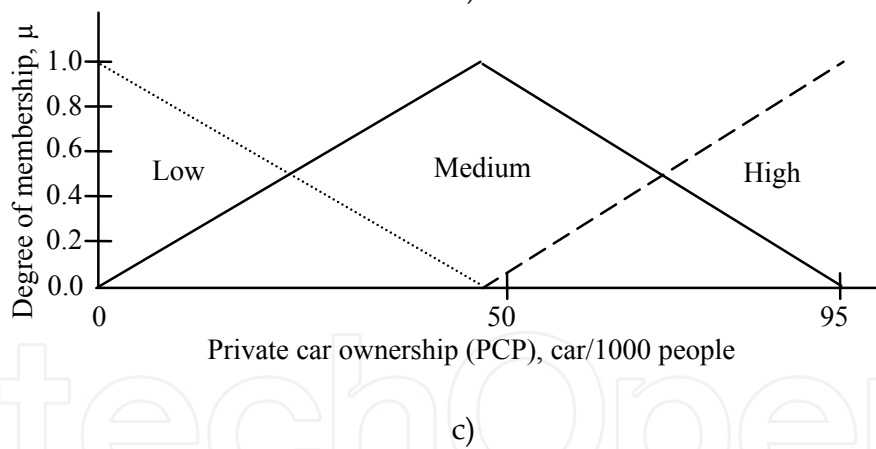
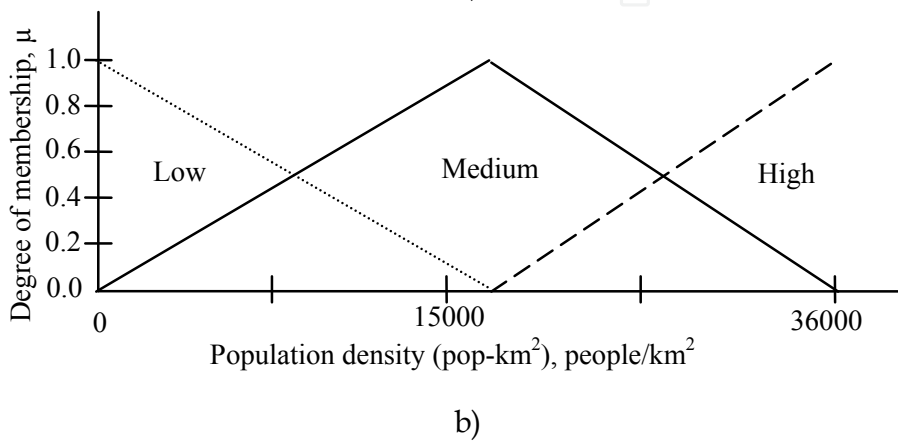
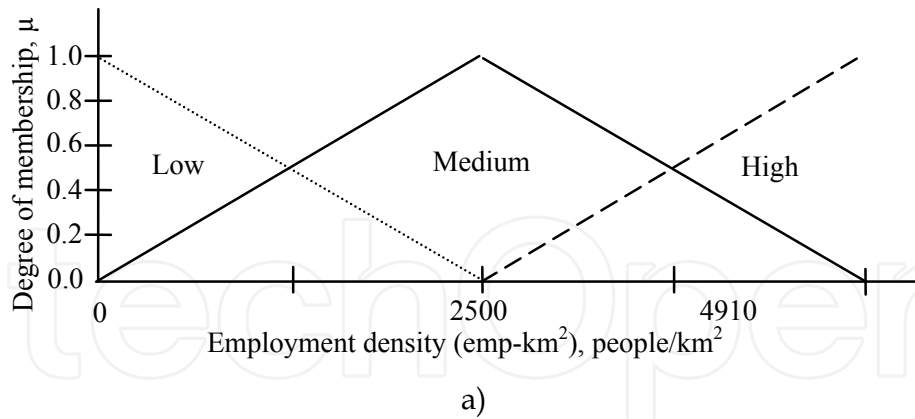


Fig. 5. Triangular Membership Function

In FMOTS, each of the input parameters has been defined by three fuzzy linguistic terms: low, medium and high. The "medium" term was considered to be the mean value of the data set and, therefore, is a single point value. Based on these concepts of the data classification, membership functions were determined for employment density (Fig 6-a), population density (Fig. 6-b) and private car ownership (Fig. 6-c). Applying a similar method of data classification, membership functions were determined for the amounts of road out of service area (Fig.6-d) and amount of roads within service area (Fig. 6-e) from GIS analysis.

A triangular membership function is therefore used (Fig 6 a-e). The output parameter, on the other hand, is consisted of five linguistic terms: very_low, low, medium, high and very_high (Fig 6-f).

By creating a rule base for the FMOTS, the available data are used in addition to experts' knowledge. The experts are specialized in traffic and transport engineering and city and regional planning. By FMOTS, for each of the 5 input parameters, 3 linguistic terms are defined, which makes a total number ($3^5 = 243$) rules. However, in the model, 189 meaningful rules have been used. In Table 1, a part of the rule base is seen.



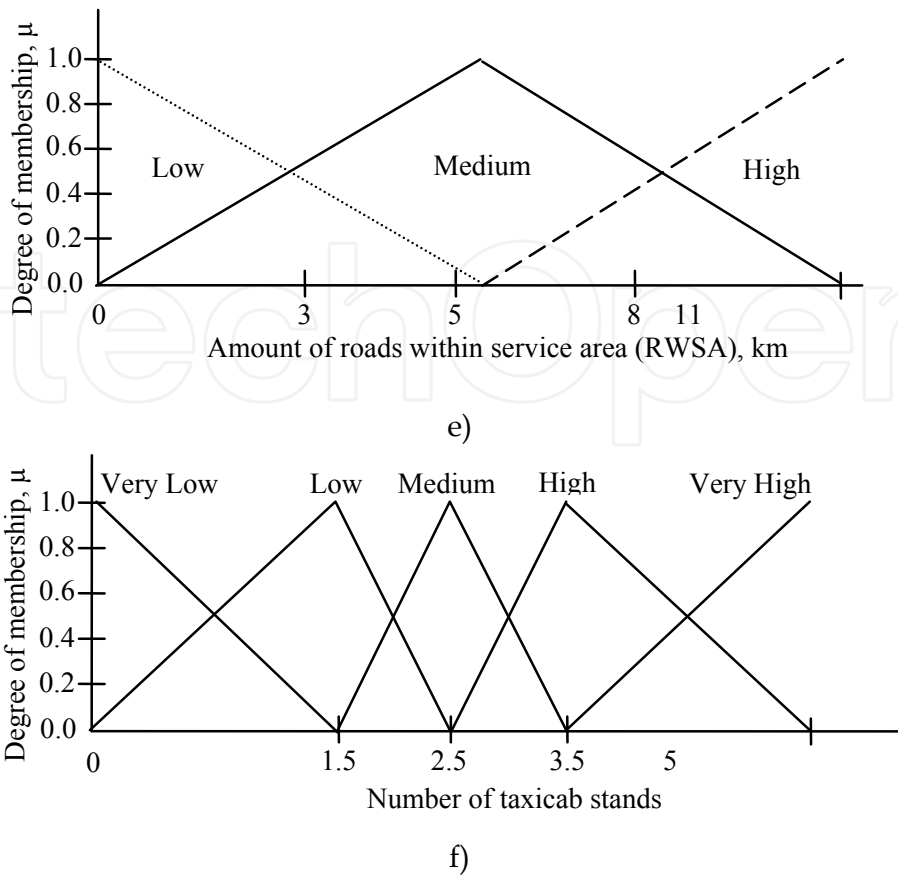


Fig. 6. Membership function of input parameters (a-e) and output parameter (f)

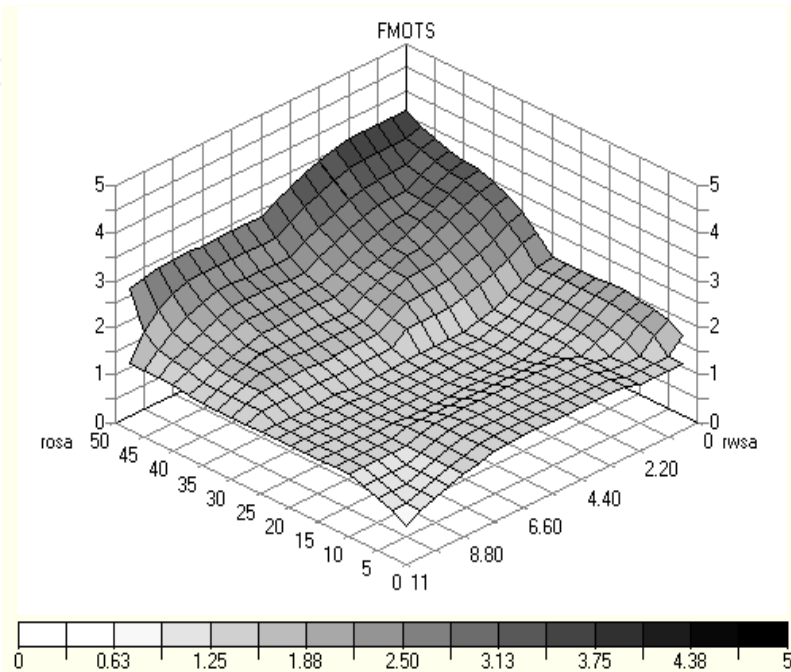
Number of the rule	If					Then
	Emp/km2	Pop/km2	Private Car per 1000 Persons (PCP)	Roads Outside Service Area (km) (ROSA)	Roads Within Service Area (km) (RWSA)	FMOTS
1	low	low	low	low	medium	very_low
2	low	low	high	low	medium	medium
3	medium	medium	medium	low	medium	medium
4	high	high	medium	large	low	very_high
5	medium	medium	high	high	low	medium

Table 1. A part of the rule base of the FMOTS

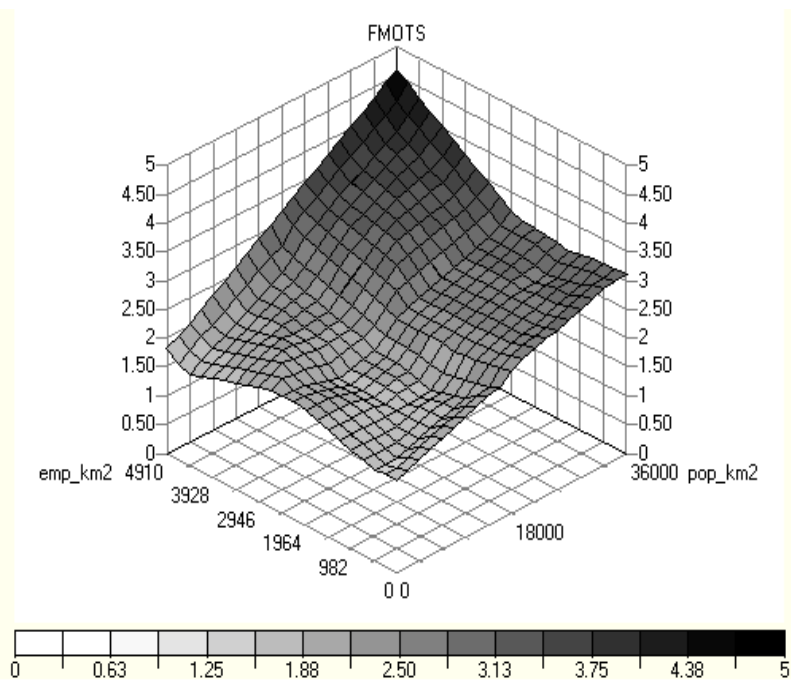
By developing FMOTS, a fuzzy logic expert system software has been used. In the model, CoM defuzzification mechanism has been managed. No weightings were applied, which means no rule was emphasized as more important than others. In this phase, a crisp value is achieved by defuzzification of the fuzzy value, which is defined with respect to the membership function. In other words, FMOTS defines the necessary number of taxicab stands for each zone, with respect to the input parameters.

5.1 Findings and comparisons

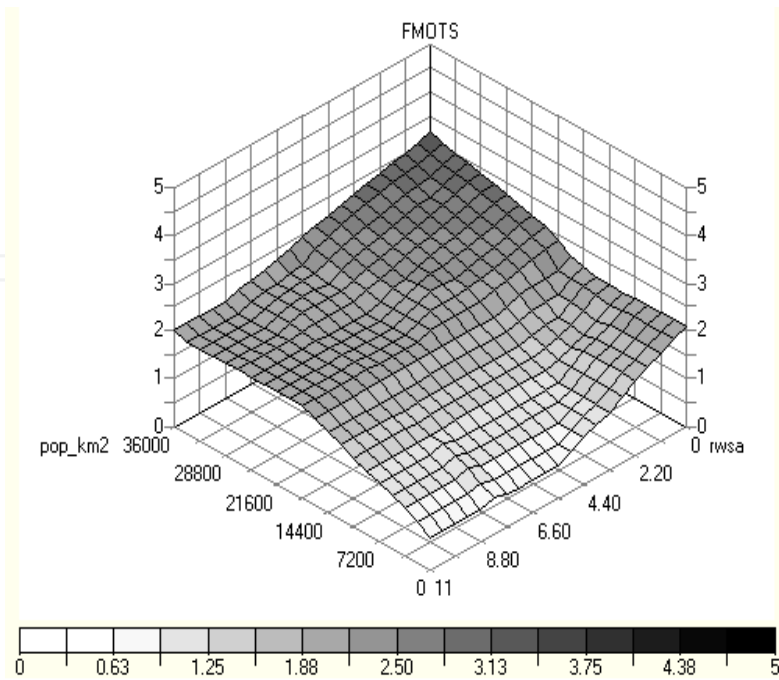
In this study, some findings are reached. In Fig.7, some main findings of the study are presented in 3D graphics. As seen in the figure, the parameter combinations have different influences on FMOTS.



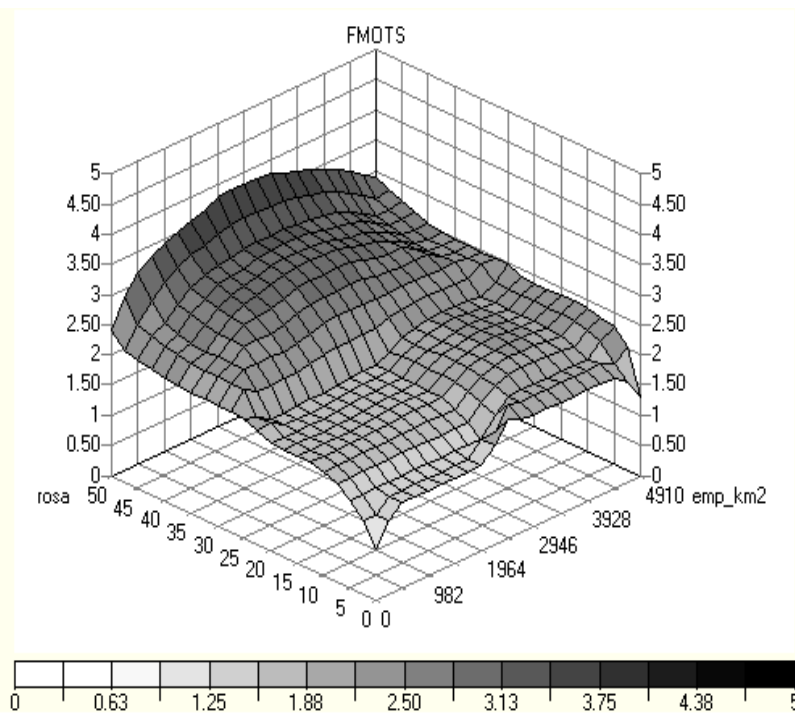
(a)



(b)



(c)



(d)

Fig. 7. Three dimensional representation of some selected variables on FMOTS: (a) RWSA-ROSA relationship; (b) Emp/km2-Pop/km2 relationship; (c) RWSA-Pop/km2 relationship; (d) ROSA-Emp/km2 relationship.

In Fig.7-a, with an increase of roads within accessed area and an increase of roads outside accessed area, an increase in necessary taxicab stands is represented. In the researched area, in the worst condition (ROSA=50 and RWSA= 0) the number of maximum taxicab stands is 4.

In Fig.7-b, population and employment potentials have a strong influence on the number of taxicab stands. Increase of both of these inputs increase also the number of necessary taxicab stands.

In Fig 7-c, increase of population density, together with a decrease in roads within service area decrease the number of necessary taxicab stands in that zone. A low population density together with a high level of roads within accessed area decrease the number of necessary taxicab stands in that zone.

In Fig. 7-d, the relationship between the employment density and the amount of roads without service area is demonstrated. In the model, if the amount of roads without service area exceed 25 km, the need for taxicab stands increase in that area. For a population density of 3000 people per km² and for maximum amount of roads outside accessed, 4 taxicab stands are needed.

6. Conclusions

In this study, an integrated model of GIS and fuzzy logic, FMOTS, for taxicab stand location decision is used. The model is based on fuzzy logic approach, which uses GIS outputs as inputs. The study brings some innovation by implementing fuzzy logic to a transport problem for an area based analysis, different from the others that focus on networks and queuing theory.

The model for location decisions of taxicab stands brings an alternative and flexible way of thinking in the problem of a complex set of parameters by integrating a GIS study and fuzzy logic.

FMOTS gives some results to evaluate the necessary number of taxicab stands in traffic zone level, which are consistent with the observations of the planners.

The scale of the analyzed area requires specific methods to compute the data, such as the areas which do not have adequate taxi service. GIS based service area analyses helped to define the area, which can be accessed from taxicab stands within a psychologically accepted time limit (and critical areas that are out of service range). The obtained data were useful in fuzzy operations.

FMOTS addresses many of the inherent weaknesses of current systems by implementing: a) fuzzy set membership as a method for representing the performance of decision alternatives on evaluation criteria, b) fuzzy methods for both parameter weighting and capturing geographic preferences, and c) a fuzzy object oriented spatial database for feature storage. These make it possible to both store and represent query results more precisely. The end result of all of these enhancements is to provide spatial decision makers with more information so that their decisions will be more accurate.

The location decisions of taxicab stands in Konya have been examined by this integrated model and their appropriateness has been evaluated according to the selected parameters. Despite lack of useful data in some newly developed areas, consistent results could be achieved in determining the necessary number of taxicab stands for city cells. The consistency of the model can be increased if the infrastructure of the districts is improved and some other necessary data are collected. In addition, definition of some other input parameters would help development of the FMOTS model.

The proposed fuzzy logic model is indeed a decision support system for decision makers, who wish to alleviate taxicab stand complexity in the short to medium term. Taxi and its control systems can make use of the vague information derived from the natural environment that in turn can be fed into expert systems and so provide accurate recommendations to taxi drivers, the customers, motoring organizations and local authorities.

Broad future research can be suggested with the study. The model can be developed for a decision support system for determining the necessary number of taxicabs assigned for each of the taxicab stands in an urban area.

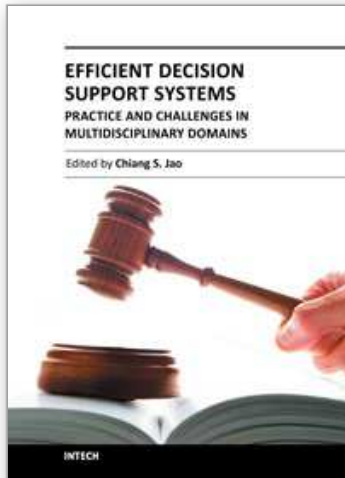
7. Acknowledgement

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