How urban managers can use DSS to facilitate decision making process: an application of fuzzy TOPSIS

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Abstract: Urban authorities have to deal with various, sometimes conflicting, and multi-dimensional issues which brings a great deal of complexity to the planning process. As a result, they need suitable tools to support making rational decisions and overcoming the complexity. Decision support systems (DSSs) are one of the effective tools used worldwide to improve the quality of decision making process. As designing an efficient decision support system requires adequate data gathering and model developing, in most cases DSS development is a costly and time consuming project. Therefore, it doesn't seem to be logical or sometimes feasible to apply it for urban management areas and the authorities should follow a logical process to choose the most appropriate area for using DSS. The aim of this paper is to propose a multi-criteria decision making model based on fuzzy TOPSIS to pave the way for urban managers in order to benefit from DSS in decision making process. The detailed specification of the model besides the algorithm to be followed is described and a numerical example is presented to clarify the model.
[Farzad Torkamani, Samira Fallah, Masood Saadatmand. **How urban managers can use DSS to facilitate decision making process: an application of fuzzy TOPSIS.** J Am Sci. 2012; 8(5):162-173]. (ISSN: 1545-1003). http://www.americanscience.org. 21

Keywords: Decision Support System, Urban Management, Decision Making, Fuzzy Set Theory, TOPSIS

1. Introduction

The population of urban areas is growing annually, according to UN reports more than half of people all over the world are now living in urban areas, and it is expected that by the year 2050, near 70% of world's population will be urban ("World Urbanization Prospects: The 2009 Revision," 2009). This rapid urbanization makes new challenges for urban authorities and may results in various problems if cities are not managed properly. On one hand, cities must be prepared to fulfill the requirements of inhabitant and guarantee their expected quality of life; necessary infrastructures and facilities including energy and supplies, health, education and entertainment as well as sewage system and garbage gathering system must be prepared through rethinking about current infrastructures while planning for new ones. Also cities, as the drivers of economy, need an efficient transportation system to facilitate smooth mobility, as in dense cities traffic congestion reduces productivity and results to huge costs. Besides financial and economic challenges, for having a sustainable city, some social and environmental issues such as air quality, noise pollution and energy consumption must be taken in to consideration to ensure preserving resources for the generations to come.

As the result, in the process of planning and decision making for urban areas, various and sometimes conflicting objective functions must be dealt which made the process very complex. This arise the need for complete and quality data as well as effective tools to facilitate the use of advanced analysis and modeling. Information Systems (IS) are among the best supportive tools for fulfilling these requirements and reducing the complexity of planning process. Variety in types and applications of information systems facilitates their usage in urban management, while transaction processing systems (TPS) could support operational decisions; executive information systems (EIS) are helpful for the strategic ones and decision support systems (DSS) could be applied to wide range of cases, from strategic decision about a new waste treatment system to the operational concern of how to change the timing of a traffic light. In addition, this type of information systems supports both individual and group decision making and does not replace individual judgments while improving the effectiveness of decision making process (Oddrun Uran, 2003). As the result, DSSs are useful tools to help urban authorities with providing necessary information as well as decision support techniques to analyze specific problems or opportunities.

However, on one hand, as stated previously there are a wide range of issues which have to be dealt form strategic to tactical levels such as managing infrastructures, concerning sustainability, providing necessary supplies, managing road traffic, designing urban areas etc. In most of these areas DSS could come in handy to evaluate different scenarios and facilitate decision making. But on the other hand, in most occasions developing a DSS is costly and time consuming which requires huge efforts. As the result it is not possible to use this system for all types of decisions and the authorities need pace a rational and reliable route to rank and choose the appropriate areas for using DSS that are the most beneficial. In this paper a Fuzzy TOPSIS model is proposed which supports the authorities to choose the major area to apply DSS.

Firstly for having a realistic insight and clarifying the areas of urban planning which DSS could be used, we reviewed some of the studies and cases in current literature. Identifying the cases and studies, the next step was categorizing them as certain areas in urban management concerns and the final step was proposing a model to choose between various areas based on some certain criteria and a rational algorithm. The detailed specification of the model besides the steps of an algorithm to apply it is presented and a numerical example is also explained to deepen the understanding of the model.

The rest of the paper is organized as the follow: Section 2 presents a brief overview of information systems and particularly DSS. Section 3 is dedicated to reviewing current literature on multi criteria decision making in urban management and clarifying the shortcoming of current studies. In Section 4, we review some of the applications of DSS in specific areas of city logistics with the aim of clarifying the broadness of potential areas for using DSS. In section 5, the proposed model and a step by step algorithm is described which more clarified by a numerical example in section 6. Finally section 7 summarizes the paper.

2. An overview of Decision Support Systems

For making right decisions, right information is needed. High quality information has three attributes. The first is its time; up-to date information about past, present and future must be accessible in any time. The second is its content; information must be accurate, relevant and comprehensive as well as concise which fulfill the exact requirements of users. And the last one is its form; information must be clear and be provided in the form of printed paper documents, video displays, etc. Providing high quality information for a decision maker is not easy, especially when different data from various sources must be collected. In many cases, DSSs are the best solution. (O'Brien, 2004)

Today, DSS have become a significant domain of IS research. Burstein and Holsapple (2008) define the term as "systems which represent and process information for the purpose of improving decision making". Also O'Brien (2004) defines DSS as computer-based systems that provide interactive information support to managers and business professionals during the decision making process. DSS can range from a simple spreadsheet to sophisticated data warehousing and mining applications, knowledge management systems, or modeling systems.

3. Literature Review

Urban authorities have to concern about a wide range of issues while most often the available resources are limited. This makes decision makers to choose between various projects and areas by considering different and sometimes conflicting criteria (Wann-Ming Wey, 2007). As the result, the process of making decision about urban issues is mostly multi criteria. In addition applying DSSs to facilitate decision making is also a costly and time consuming process, consequently it is not possible and even logical to apply them in all areas of urban management. Therefore, decision makers have to firstly determine the most appropriate and beneficial projects to fund and to apply DSS.

Reviewing the current literature on multi criteria decision making in urban management, we conclude that the common theme of most studies is concentrating on selecting between options in specific areas of urban management such as water management and transportation. **Error! Reference source not found.** shows some researches in chronological order, which have been developed to solve minor problems considering urban management issues, DSS characteristics and multi-criteria decision making.

Table 1- Current works on urban management, DSS and MCDM

Reference	Concentration
(Vatalis & Manoliadis, 2002)	Landfill site selection
(Kuwata et al., 2002)	Evaluation of decision support systems for emergency management
(S. Juan, Quangong, Ruijun, & Wenlan, 2004)	Forage selection
(Adenso-Dıaz, Tuya, & Goitia, 2005)	Evaluation of alternatives in waste water collecting system design
(Ahmad Abrishamchi, 2005)	Application of multicriteria decision making to urban water supply
(C. K. Makropoulos, 2008)	Sustainable option selection in integrated urban water management
(Bani et al., 2009)	A review on development of decision support system for waste management
(Yilmaz & Harmancioglu, 2010)	Decision making for water resource management
(Z. Li, Madanu, S., Zhou, B., Wang, Y., Abbas, M, 2010)	Selecting highway investment alternatives
(Jeffrey Shelton, 2010)	Prioritizing transportation projects
(A.R. Karimi, 2011)	Wastewater treatment process selection
(Mantelas, Prastacos, Hatzichristos, & Koutsopoulos,	Urban growth modeling

2012)	

Along with several studies in minor areas of urban managements, there are only a few ones with a more holistic and managerial point of view, as the following:

Wann-Ming Wey (2007) addressed the urban renewal project selection problem in city of Taichung in Taiwan by proposing a model based on the Fuzzy Delphi method, the Analytic Network Process (ANP) and Zero – One Goal Programming (ZOGP). They incorporated expert judgments to calculate a priority index for each project and generated a performance ranking of them.

Wey and Wu (2008) proposed a multi-objective integer model for urban renewal project selection. Their model integrates Multi-Objective Optimization, Mont Carlo Simulation and Analytic Network Process. He suggested some criteria such as amount of available budget, chance of success and project costs.

Y. K. Juan, Roper, Castro-Lacouture, and Kim (2010) proposed a systematic approach to facilitate decision making in urban renewal project selection. They applied Porter's diamond model of competitive advantage in order to establish evaluation criteria and a fuzzy set theory while PROMETHEE method is used for determining the projects' priority. They used two major groups of criteria; sustainability and competitiveness.

As it is shown, the current literature lacks studies on the following issues:

- A comprehensive list of different application areas of DSS in urban management
- A holistic view on different applications of DSS in urban management to help managers to choose the most appropriate area
- A decision making model for the decision making process

In this paper we propose a decision model based on Fuzzy TOPSIS which support decision makers to compare between different potential areas of applying DSS for more rational urban planning. The model provides an efficient transformation of linguistic variables in order to facilitate authorities taking part in the process which has not been concentrated in previous works. These individuals will be potentially benefited from the model:

- Urban authorities:

The model not only improves the productivity of their decisions but also enlists the primary choices (areas) as inputs of decision making process (alternatives).

- DSS developers:

The model helps them to explore new areas for applying DSS in urban management.

- Programming knowledge workers who are directly responsible to facilitate and provide infrastructures, equipping developers in the way to design and implement new information systems

The research model used in this paper is as shown in Figure 1.

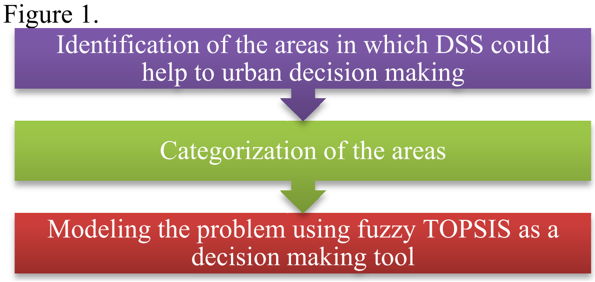


Figure 1- The research model

4. Applications of DSS in urban management

In order to identify the areas which DSS could come in handy for managing cities and understand how it facilitates decision making process for urban authorities, we reviewed the current literature. Recently, several research and studies as well as real world projects are developed which made a rich literature on applications of DSSs in urban management. In a recent survey on applications of DSS, Eom, Lee, Kim, and Somarajan (1998) reviewed the studies from 1994 to 2001. Their survey shows that urban/community planning and administration constitute near 7.14% of all DSS applications and the main areas include emergency evacuation, snow removal and disposal plan, urban transportation and manage urban waste. To have a comprehensive review on current literature, we searched "Science Direct" and "Scopus" scientific databases using various keywords including "DSS urban management" and "decision support system" in March 2011. In these searches, more than 500 articles were found and studied. Consequently, 76 articles were selected as the most related ones. These papers include case studies and other researches about various applications of DSS in urban management summarized as in Table 2.

4.1. Transportation

DSSs are widely applied in transportation planning and management. Transportation is the major component of any logistics system and particularly city logistics. Today, having an efficient and effective transportation system which facilitates smooth mobility is a must for any city to save time and energy, increase productivity and reduce pollution costs. Due to the fact that transportation constitute the biggest portion of logistics costs, for instance in US around 6% of GDP is consumed for transportation (Cooke, 2006).

Table 2.Categorization of the application areas for DSS in urban management

Area (category)	References
Transportation	(Zhou, Thill, & Huang, 2011), (Jing, Quchen, & Yanping, 2010) , (Kepaptsoglou, Karlaftis, & Bitsikas, 2010), (Jradi, do Nasciment, Longo, & Hall, 2009), (He & Zhang, 2009), (Sidi, Hammadi, Hayat, & Borne, 2008), (YAN, YANG, & GUAN, 2008), (Almejalli, Dahal, & Hossain, 2007), (Chou, Caldas, & O'Connor, 2007), (Hu & Lu, 2007), (Ülengin, Önsel, Ilker Topçu, Aktaş, & Kabak, 2007), (Cooke, 2006) , (Melki & Hammadi, 2006), (Bouamrane, Tahon, Sevaux, & Beldjilali, 2005),(Arampatzis, Kiranoudis, Scaloubacas, & Assimacopoulos, 2004), (Y. H. Wu, Miller, & Hung, 2001), (Burla, Laniado, Romani, & Tagliavini, 2001), (Bielli, 1992), (Cochran & Chen, 1991)
Sustainability	(C. I. Wu, Liu, & Tsai, 2011), (Denzer, Schlobinski, & Gidhagen, 2011), (Huizar Jr, Kang, & Lansey, 2011),(Shi & Li, 2010), (Nijkamp, Borzacchiello, Ciuffo, & Torrieri, 2007), (Boitsidis, Gurnell, Scott, Petts, & Armitage, 2006), (Kazmukova, Janota, & Pisa, 2006), (Banai, 2005), (Cellura, Beccali, & Mistretta, 2002), (Y. C. Chang & Chang, 2002), (Bakonyi et al., 1997)
Air Quality	(Elbir et al., 2010), (Toscani, Bargna, Quarenghi, Archetti, & Giordani, 2010) (Vlachokostas et al., 2009), (Jensen, Berkowicz, Sten Hansen, & Hertel, 2001)
Water Management	(Pearson, Coggan, Proctor, & Smith, 2010), (Christodoulou & Deligianni, 2010), (Elmahdi & McFarlane, 2009), (Andreu, Ferrer-Polo, Pérez, & Solera, 2009), (Santos, Coutinho-Rodrigues, & Current, 2008), (Berlekamp, Lautenbach, Graf, Reimer, & Matthies, 2007), (C. K. Makropoulos, 2008) , (Bo-ping, Guo-xi, & Shi-yu, 2008), (Silva & Maia, 2007), (Maia & Schumann, 2007), (Davis, 2000), , (Simon, Brüggemann, & Pudenz, 2004), , (Barros, Brandão, & Hamburger, 2004), (Hadzilacos et al., 2000)
Waste Management	(Banias, Achillas, Vlachokostas, Moussiopoulos, & Papaioannou, 2011), (Caballini, Giribone, Revetria, & Testa, 2010) , (Repoussis, Paraskevopoulos, Zobolas, Tarantilis, & Ioannou, 2009) ,(van Overloop & Nava, 2008), (Smith, Lejano, Ogunseitan, & Hipp, 2007), (Vuppala, Asadi, & Reddy, 2006), (Costi, Minciardi, Robba, Rovatti, & Sacile, 2004), (Dinesh & Dandy, 2003), (Fiorucci, Minciardi, Robba, & Sacile, 2003), (Bazzani, 2000), (Haastrup et al., 1998), (Massam, 1991)
Urban Infrastructure Management	(Christodoulou, Deligianni, Aslani, & Agathokleous, 2009), (Jajac, Knezic, & Marovic, 2009), (Halfawy, Dridi, & Baker, 2008) ,(Sharma, Al-Hussein, Safouhi, & Bouferguène, 2008), (Fatwanto, 2006), (Artina, Becciu, Maglionico, Paoletti, & Sanfilippo, 2005), (Quintero, Konaré, & Pierre, 2005)
Emergency Management	(Huang, Siling, Chen, Chen, & Xu, 2010), (Kupferle, Krabig, & Hirschhauser, 2009), (Mirfenderesk, 2009), (Zhang & Li, 2008), (Qi-min, 2006), (Abebe & Price, 2005), (Labelle, Langevin, & Campbell, 2002), (Todini, 1999), (N. B. Chang, Wei, Tseng, & Kao, 1997), (Navarro & Garcia, 1996)

As the result, having an efficient approach for creating effective scenarios in transportation planning is essential. Arampatzis et al. (2004) designed a DSS to assist transport administrators enhance the efficiency of the transportation supply, while improving environmental and energy indicators. The model allows estimation of traffic flow patterns within each link of the road network starting from the knowledge of the network characteristics and traffic demand. Energy consumption and pollutant emission calculations are based on the methodology developed by the 'CORINAIR' working group. Also Y. H. Wu et al. (2001) presented a GIS-based DSS for dynamic network congestion modeling and minimum cost routing. Burla et al. (2001) worked on this field and described the role of DSS to reforming public transportation in Lombardy, Italy. Ülengin et al. (2007) developed an integrated DSS to formulate aggregate and long-term transportation scenarios for Turkish transportation master plan. Jing et al. (2010) designed a DSS to solve the Shanghai transportation problem from the decision-making process towards to sustainability.

4.2. Sustainability

Previously, most of the objective functions in different areas were focused mainly on economic aspects but the major focus of sustainability is on social as well as environmental issues. The aim of sustainability is to satisfy human needs while preserving the environment for generations to come. For analyzing and optimizing current urban systems as well as planning future systems, innovative and scientific tools are required and DSSs are among the bests.

Cellura et al. (2002) presented a multi-criteria DSS in order to assess the environmental performance of urban systems and define suitable scenarios to control the developing trends toward sustainability they applied the system in Palermo, Italy.

Nijkamp et al. (2007) developed a decision support system to ensure sustainable mobility in Naples, Italy which is capable of designing land use/transportation plans, multi criteria analysis and testing the robustness of policy rank order solutions.

Banai (2005) developed a DSS prototype to aid in the assessment of incremental land development plan proposals using analytical hierarchical process (AHP) Banai's DSS incorporates multiple sustainability criteria, weighted strategically responsive to local public policy priorities and community-specific situation and values, while gauging and directing desirable future courses of development.

4.3. Air quality

One of the primary areas for applying DSS in urban management is assessing air quality. Jensen et al. (2001) developed a new prototype model system named AirGIS to support local authorities in air quality management for big cities in Denmark. Lim, Hughes, and Hellawell (2005) presented a system to solve the problem of predicting potential atmospheric pollution problems in a timely, efficiently way in comparison with the ones proposed by other academicians In the United Kingdom. Vlachokostas et al. (2009) presented an integrated assessment methodological scheme to systematically evaluate air pollution control measures in Thessaloniki, Greece.

4.4. Water management

Manipulating as a managerial tool in the area of water management is one of the most common types of DSS applications in urban areas.

Davis (2000) offered an agent based decision making model, supporting database reclamation, data warehousing, water mains pipe-failure prediction and strategic overview information

Makropoulos, Natsis, Liu, Mittas, and Butler (2008) described the development of a decision support tool known as Urban Water Optioneering Tool (UWOT) to facilitate selecting combinations of water saving strategies and technologies and to support the delivery of integrated, sustainable water management for new developments.

Simon et al. (2004) did a research and designed a DSS for evaluation of water management strategies in Berlin and Potsdam, with respect to their ecological effects in 14 sections of the surface water system.

Another recent publications which uses DSS as a supporting tool to facilitate solving water management problems, is what Pearson et al. (2010) developed. They tried to assist managers in the urban water industry to analyze a mix of water service options, at the whole-of-city scale. Their approach provides a transition from traditional command and control approaches tending to focus on an outcome at a point in time, to a more sustainable, inclusive and dynamic decision-making process driven by social learning and engagement.

4.5. Waste management

As another important urban management issue, waste management also has attracted attentions in recent years. Waste management is very complex, because it usually consists of several conflicting problems that must be dealt while considering the social and environmental issues. Among them are locating disposal site, choosing transportation system, reducing the total waste, recycling. DSS could be helpful in overcoming these complexities.

Santos et al. (2008) developed a spatial decision support system (SDSS) for trash collection vehicle routing in Coimbra, Portugal.

Haastrup et al. (1998) developed a decision support system for urban waste management, to be used for evaluating general policies for service organization of the waste collection and identifying areas suitable for locating waste treatment and disposal

Fiorucci et al. (2003) developed and applied a DSS to assist the planner in decisions concerning the overall management of solid waste at a municipal scale. Their DSS allows to plan the optimal number of landfills and treatment plants, and to determine the optimal quantities and the characteristics of the refuse that has to be sent to treatment plants, to landfills and to recycling.

Costi et al. (2004) structured and applied a DSS to enhance the productivity of managerial efforts on the urban solid wastes. Their aim was to help the authorities developing incineration, disposal, and treatment and recycling integrated programs.

4.6. Urban infrastructure management

Another important area to discuss is utilizing DSS in order to solve urban infrastructure managerial problems. Because in most cases, majority of participants, multi- disciplinarily, huge quantity of information, limited budget, conflict goals and criteria makes the infrastructure management really complex.

Quintero et al. (2005) provided an intelligent DSS suitable for coordinated management of urban infrastructures. Identifying the data and related treatments common to several municipal activities, the system defines the requirements and functionalities of the computer tools to improve urban infrastructure management in terms of delivery, performance and coordination of municipal services to the population.

Jajac et al. (2009) developed a DSS to deal with urban infrastructure management in terms of maintenance. They proposed a system which starts with goal analysis followed by defining urban infrastructure elements and developing adequate criteria set.

4.7. Emergency management

Cities must be prepared to manage the crisis and emergencies, due to the fact that man-made and natural disasters such as terrorist attacks, hurricanes, earthquakes, floods, etc. are always probable. DSSs could help the authorities in managing crises by providing a better understanding of the situation. In emergencies accessing real time data and monitoring the event while having a good coordination between people and organizations involved is very important and DSSs could help satisfying these requirements.

Zhang and Li (2008) presented present an open DSS for urban emergency which is capable of responding to a variety of urban contingencies.. Their system composed of a spatial database management system, integrated simulation modeling system, a Digital City Infrastructure Service Platform (CyberSIG) and a decision support subsystem. The subsystems support data enrolment and withdrawn in to and from DSS, indeed it is able to integrate the required data from different organizations involved in emergency.

Abebe and Price (2005) represented a DSS for flood management in urban areas. The system assists the authorities to plan emergency activities by flood warning module and give guidance for restoration tasks after flood. Their target areas are Liguria Region in Italy and the Greater Athens in Greece.

Todini (1999) described the development of an integrated tool which considers different groups of experts such as operational managers, meteorologists/hydrologists and civil response managers to participate in flood management. Their tool is able to allow locating of areas at risk and estimation of expected damages and forecast floods and inundation phenomena. It is also capable of evaluating the effects of decisions and continuous training of personnel.

5. Decision making model

In order to make decision about the most appropriate fields which DSS should be developed in urban management problems in a particular city, some certain criteria must be used to make it possible for the authorities to compare the different areas. In this paper, we proposed three major criteria:

- *Maturity of available literature*
  Having a rich literature with various decision making models as well as different real world applications of DSS make it easier for decision maker to implement a system, as there are more “best practices” in hand.
- *Feasibility of implementation*
  If an area is more feasible in terms of DSS design and implementation, it will be more appropriate for the urban decision maker to invest on it.
- *Significance of area for achieving urban vision*
  Urban decision makers are more willing to invest in areas which are more significant to achieve urban vision and solve current problems of a city.

Besides the appropriate criteria, a reliable decision making process should be paced to ensure choosing the best. We present a fuzzy TOPSIS model which used the criteria and suggest the best solution.

5.1. Fuzzy TOPSIS

The TOPSIS technique proposed by Hwang and Yoon (1981) is a well-known classic decision making method in case of having several conflicting criteria affecting the selection process. Various researches have extended different attributes of the technique leading to more efficient approaches. For more information see (Chen, 2000; Triantaphyllou & Lin, 1996; Tsaur, Chang, & Yen, 2002).

Because the proposed criteria in the previous section have a great deal of natural vagueness, TOPSIS is equipped with fuzzy set theory (Zadeh, 1965) and linguistic data (a type of data which consists of words or sentences (Zadeh, 1975)) to represent this vague nature. To weigh the criteria used in the decision making model,

Table *3* will be utilized. To review some previous researches using similar transformation of linguistic data into fuzzy numbers to make decisions, interested readers are referred to (Ayağ & Özdemir, 2006; Chu, 2002; Chu & Lin, 2003; Ertuğrul & Karakaşoğlu, 2008; Esmaili & Torkamani, 2010; D. F. Li, 2007; Önüt, Soner Kara, & Efendigil, 2008; Safari, Fathi, & Faghih, 2011; Sotoudeh Gohar, Khanzadi, & Parchami Jalal, 2011; Yong, 2006). Among various extensions of fuzzy TOPSIS, this paper utilizes the one inspired by Azar and Rajabzadeh (2010).

Table 3.Linguistic variables for weight of each criterion

Linguistic term	Abbreviation	Triangular fuzzy number
Very Low	VL	(0, 0, 0.1)
Low	L	(0, 0.1, 0.3)
Medium Low	ML	(0.1, 0.3, 0.5)
Medium	M	(0.3, 0.5, 0.7)
Medium High	MH	(0.5, 0.7, 0.9)
High	H	(0.7, 0.9, 1)
Very High	VH	(0.9, 1, 1)

For evaluating each role, choices which determine how DSS can help to decision makers, we used variables shown in

Table *4*.

Table 4. Linguistic variables for valuation of each choice

Linguistic term	Abbreviation	Triangular fuzzy number
Very Poor	VP	(0, 0, 1)
Poor	P	(0, 1, 3)
Medium Poor	M	(1, 3, 5)
Fair	F	(3, 5, 7)
Medium Good	MG	(5, 7, 9)
Good	G	(7, 9, 10)
Very Good	VG	(9, 10, 10)

In case of having k persons as decision makers, then $\tilde{x}_{ij}$ and $\tilde{w}_j$ will be calculated using the following equations.

$$\tilde{x}_{ij} = \frac{1}{k}\left[\tilde{x}_{ij}^{1}(+)\tilde{x}_{ij}^{2}(+)\ldots(+)\tilde{x}_{ij}^{k}\right]$$

$$\tilde{w}_{j} = \frac{1}{k}\left[\tilde{w}_{j}^{1}(+)\tilde{w}_{j}^{2}(+)\ldots(+)\tilde{w}_{j}^{k}\right]$$

Where $\tilde{x}_{ij}^k$ and $\tilde{w}_j^k$ represent: the valuation result of decision maker k and the weight of decision maker k respectively. In this case, all fuzzy numbers are triangular, so:

$$\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}) \quad (3)$$

$$\tilde{w}_{ij} = (w_{j1}, w_{j2}, w_{j3}) \quad (4)$$

In the next pace, normal fuzzy decision matrix $\tilde{R}$ will be calculated using the following equation:

$$\tilde{R} = [\tilde{r}_{ij}]_{m\times n} \quad (5)$$

Where, m is the number of choices (here m=7) and n is the number of criteria (3 here).

$\tilde{r}_{ij}$ Is calculated as follows:

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{d_j^*}, \frac{b_{ij}}{d_j^*}, \frac{c_{ij}}{d_j^*}\right) \quad (6)$$

$$d_j^* = \max_j\{a_j^*, b_j^*, c_j^*\} \quad (7)$$

$$a_j^* = \max_j a_{ij} \quad (8)$$

$$b_j^* = \max_j b_{ij} \quad (9)$$

$$c_j^* = \max_j c_{ij} \quad (10)$$

Using the following equations, weighted normalized fuzzy decision making matrix is constructed:

$$\tilde{V} = [\tilde{v}_{ij}]_{m\times n}, i = 1, \dots, m, j = 1, \dots, n \quad (11)$$

For all i and j, $\tilde{v}_{ij}$ are normalized triangular fuzzy numbers.

Because the TOPSIS method, tries to find a choice having nearest to the best solution and farthest to the worst one, the next phase, consists of calculating the positive-ideal solution and negative-ideal solution.

$$A^+ = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*) \quad (12)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-) \quad (13)$$

Where $(j = 1, \dots, n)$:

$$\tilde{v}_j^* = (1,1,1) \quad (14)$$

$$\tilde{v}_j^- = (0,0,0) \quad (15)$$

For every choice, the distant to A^+ and A^- can be calculated as follows:

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*), i = 1, \dots, m \quad (16)$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-), i = 1, \dots, m \quad (17)$$

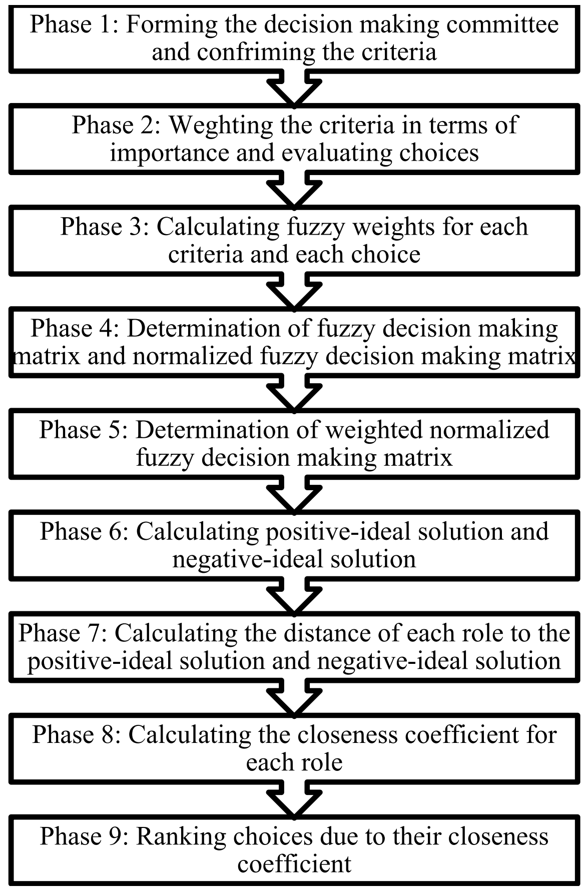
At last, a closeness coefficient should be assigned to every choice using the following equation:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad (18)$$

For the choice which CC_i is more, it means that it is more appropriate to be invested in than other choices.

5.2. Model finalization

An algorithm to help using the proposed model is as depicted in **Error! Reference source not found.**.



6. A numerical example

In this section, a numerical example is explained to deepen the understandings of the proposed model. Consider city of Tehran as an example, having four decision makers. The hierarchy of the problem is shown in Figure 2.

The four decision makers (DMs) ranked the three criteria in terms of importance. Results of their rankings are presented in

Table *5*.

Table 5- How decision makers ranked the criteria

	DM_1	DM_2	DM_3	DM_4
C_1. Decision makers' readiness	H	VH	MH	VH
C_2. Feasibility of implementation	VH	VH	VH	H
C_3. Problem solving strength	VH	H	H	MH

The results after valuation of the seven areas are as presented in Table 6.

Besides, using equations (1)-(4) **Error! Reference source not found.** contains each area's triangular fuzzy number and also fuzzy weights to each criterion.

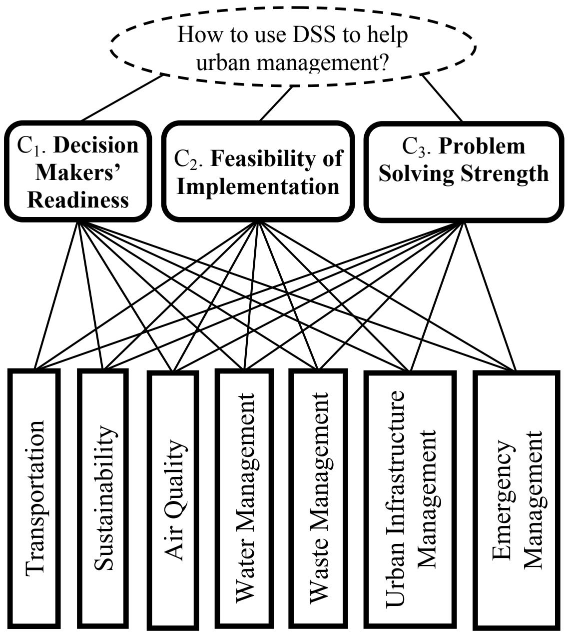


Figure 2- The hierarchy of assumed problem

Table 6- Primary Results

Area Code	C_1			
	DM_1	DM_2	DM_3	DM_4
A_1	G	VG	MG	G
A_2	MP	F	MP	F
A_3	MG	MG	F	MP
A_4	VP	VG	P	VP
A_5	F	MG	P	G
A_6	G	VP	MP	VP
A_7	MG	F	G	P

Area Code	C_2			
	DM_1	DM_2	DM_3	DM_4
A_1	VG	MP	MP	MP
A_2	F	P	VG	VG
A_3	VG	VP	G	VG
A_4	F	MP	MP	F
A_5	F	P	MP	F
A_6	MG	P	G	MP
A_7	MP	P	VP	F

Area Code	C_3			
	DM_1	DM_2	DM_3	DM_4
A_1	F	P	G	MG
A_2	P	MP	VP	P
A_3	MP	VP	VG	MG
A_4	VG	MP	P	F
A_5	G	MP	P	F
A_6	VP	MG	F	MP
A_7	G	F	MG	MP

Table 7. Fuzzy Decision Making Matrix and Fuzzy Weights

Area Code	C_1	C_2	C_3
A_1	(7, 8.75, 9.75)	(3, 4.75, 6.25)	(3.75, 5.5, 7.25)
A_2	(2, 4, 6)	(5.25, 6.5, 7.5)	(0.25, 1.25, 3)
A_3	(3.5, 5.5, 7.5)	(6.25, 7.25, 7.75)	(3.75, 5, 6.25)
A_4	(2.25, 2.75, 3.75)	(2, 4, 6)	(3.25, 4.75, 6.25)
A_5	(3.75, 5.5, 7.25)	(1.75, 3.5, 5.5)	(2.75, 4.5, 6.25)
A_6	(2, 3, 4.25)	(3.25, 5, 6.75)	(2.25, 3.75, 5.5)
A_7	(3.75, 5.5, 7.25)	(1, 2.25, 4)	(4, 6, 7.75)
Criteria Weights	(0.8,0.925,0.967)	(0.875,0.975,1)	(0.725,0.875, 0.967)

The plots of fuzzy triangular numbers achieved from **Error! Reference source not found.** are depicted in **Error! Reference source not found.**, Figure 4 and Figure 5.

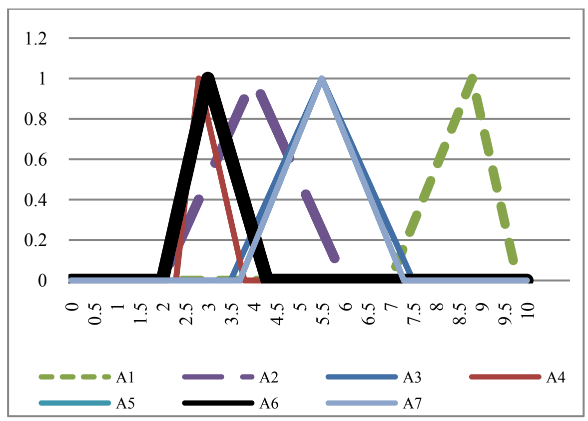


Figure 3. Triangular fuzzy numbers - criterion 1. decision makers' readiness

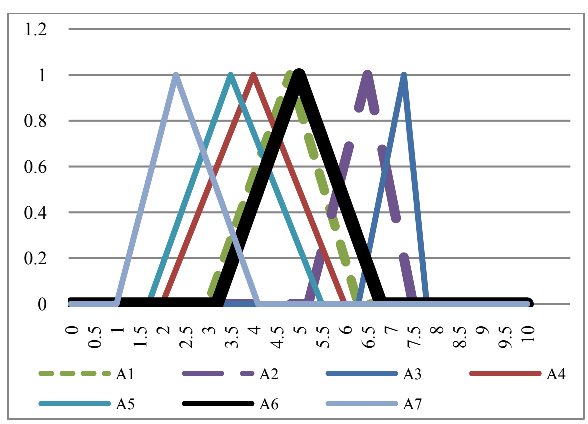


Figure 4. Triangular fuzzy numbers - criterion 2. Feasibility of implementation

Utilizing equations (6)-(11) decision makers are able to have each area's normalized value, come in Table 8 and weighted normalized values presented in Table 9.

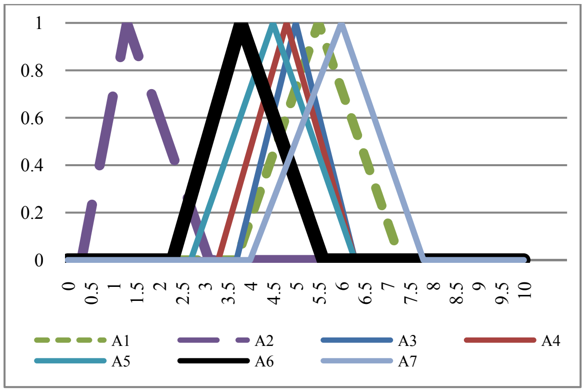


Figure 5. Triangular fuzzy numbers - criterion 3. Problem solving strength

Table 8. Normalized Fuzzy Decision Making Matrix

Area Code	C_1	C_2	C_3
1	(0.718,0.897,1)	(0.387,0.613,0.806)	(0.484,0.710,0.935)
2	(0.205,0.410,0.615)	(0.677,0.839,0.968)	(0.032,0.161,0.387)
3	(0.359,0.564,0.769)	(0.806,0.935,1)	(0.484,0.645,0.806)
4	(0.231,0.282,0.385)	(0.258,0.516,0.774)	(0.419,0.613,0.806)
5	(0.385,0.564,0.744)	(0.226,0.452,0.710)	(0.355,0.580,0.806)
6	(0.205,0.308,0.436)	(0.419,0.645,0.871)	(0.290,0.484,0.710)
7	(0.385,0.564,0.744)	(0.129,0.290,0.516)	(0.516,0.774,1)

Table 9. Weighted Normalized Fuzzy Decision Making Matrix

Area Code	C_1	C_2	C_3
1	(0.718,0.897,1)	(0.387,0.613,0.806)	(0.484,0.710,0.935)
2	(0.205,0.410,0.615)	(0.677,0.839,0.968)	(0.032,0.161,0.387)
3	(0.359,0.564,0.769)	(0.806,0.935,1)	(0.484,0.645,0.806)
4	(0.231,0.282,0.385)	(0.258,0.516,0.774)	(0.419,0.613,0.806)
5	(0.385,0.564,0.744)	(0.226,0.452,0.710)	(0.355,0.580,0.806)
6	(0.205,0.308,0.436)	(0.419,0.645,0.871)	(0.290,0.484,0.710)
7	(0.385,0.564,0.744)	(0.129,0.290,0.516)	(0.516,0.774,1)

Having:

$$A^+ = \{(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1)\} \quad (19)$$

$$A^- = \{(0,0,0),(0,0,0),(0,0,0),(0,0,0),(0,0,0)\} \quad (20)$$

The distances between the choices (the roles) and the positive/negative ideal solution are calculated using equation (12)-(20) as presented in Table *10*.

Table 10. Distances between areas and positive/negative ideal solutions

Area Code	Area Title	A^+	A^-	CC
1	Transportation	1.164	2.083483	0.642
2	Sustainability	1.737	1.457128	0.456
3	Air Quality	1.164	2.02277	0.634
4	Water Management	1.778	1.405694	0.442
5	Waste Management	1.631	1.595604	0.494
6	Urban Infrastructure Management	1.741	1.444985	0.454
7	Emergency Management	1.634	1.603698	0.495

Due to areas' closeness coefficient (CC) in Table *10*, final rankings are calculated and shown in Table 11.

Table 11. Areas' final ranking

Area Rank	Area Code	Area Title	CC
1	1	Transportation	0.642
2	3	Air Quality	0.634
3	7	Emergency Management	0.495
4	5	Waste Management	0.494
5	2	Sustainability	0.456
6	6	Urban Infrastructure Management	0.454
7	4	Water Management	0.442

According to Table 11, it's more appropriate for urban managers of Tehran, to utilize and develop DSS in transportation area in comparison to other areas.

7. Conclusion

Cities are the drivers of economy, so it is very important to be managed effectively. The range of issues which have to be concentrated for an effective city management is very wide while the available resources for investment on developing urban infrastructures are mostly limited. Hence, proper management of cities are highly dependent on the methods and tools which are applied by the authorities in decision making process and efficient ones result to more rational and effective decisions. ISs and particularly DSSs are among the best tools applied worldwide to improve the productivity of decision making process in broad areas and also in urban management. Despite the various benefits of DSSs in decision making process, applying it in a particular area needs some prerequisites such as availability of appropriate data, infrastructures, systems experts and etc. which make the process of using them costly and time consuming. Hence, it is not logical to apply them in all areas of urban management. With the lack of studies to prioritize the different areas of urban management to apply DSS in this paper we proposed a Fuzzy TOPSIS model and a step by step algorithm to apply it with the aim of supporting the authorities to choose the major area for applying DSS. This paper categorizes various researches to find most appropriate areas of applying DSS in urban areas and provides supportive scenarios to prioritize levels of DSS development.

Nevertheless, technical development issues and applied cases are yet to be added in future works.

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3/22/2012