STRATEGIC ANALYSIS OF SMART CITY MODEL AND SMART TRANSPORTATION WITH HESITANT FUZZY MCDM

(KARARSIZ BULANIK ÇKKV YÖNTEMLERİ İLE AKILLI ŞEHİRLERİN VE AKILLI ULAŞIMIN STRATEJİK ANALİZİ)

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LIST OF SYMBOLS

AHP	**:** Analytical Hierarchy Process
AHS	**:** Analitik Hiyerarşi Süreci
CODAS	**:** Combinative Distance-based Assessment
COPRAS	**:** Complex Proportional Assessment
ÇKKV	**:** Çok Kriterli Karar Verme
DM	**:** Decision maker
GDM	**:** Group decision making
HFL	**:** Hesitant Fuzzy Linguistic
HFLTS	**:** Hesitant Fuzzy Linguistic Term Set
HFS	**:** Hesitant Fuzzy Set
MCDM	**:** Multi-criteria Decision Making
SAW	**:** Simple Additive Weighting
SWOT	**:** Strengths, Weaknesses, Opportunities, and Threats

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ABSTRACT

Rapidly growing population and migration from rural areas to urban space have considerable impact on the problems of cities. With the increase in population, scarcity of resources, inadequate and deteriorating infrastructure, energy shortages and price instability, global environmental splurge and human health concerns and demand for better economic opportunities and social benefits have begun to increase. These difficulties not only affect the economic and social life in the cities negatively. It also deteriorates the life quality of the city inhabitants.

Smart city as a new concept has come to the forefront in the policy texts of countries as an approach that has a significant potential in the rational solution of urban problems.
It is a vision of the development of urban space that expresses the integration of urban assets and resources by utilizing information technologies. Works have been accelerated in recent years to develop smart cities that will raise the level of social prosperity in a complex network of living spaces.

Smart cities, which are based on the principle of self-management of transportation, infrastructure, and networks, are composed of many components. It is very important to establish models for cities to achieve productive results and be successful. In this thesis, a comprehensive smart city model is presented by using literature review and expert opinions. Moreover, this proposed smart city model is presented with hesitant fuzzy linguistic (HFL) multi-criteria decision-making (MCDM) approach.

The mixed structure of the smart cities evaluation involves many various and contradictory criteria. However, it is difficult to decide on, and rank smart cities when information is of uncertain nature. Sometimes decision makers (DMs) have difficulties to express their thoughts by numbers because these quantitative values are far from their

own way of thinking in daily life. Furthermore, DMs can express their opinions more comfortably with words, instead of crisp numbers. The hesitant fuzzy linguistic term set (HFLTS) overcomes the uncertainty of this MCDM problem.

In the first phase of the study, the importance degree of the smart city model components was taken from decision makers (DMs) and components are weighted by the HFL Simple Additive Weighting (SAW) method. Relationship matrix between main dimensions and components is constructed by collecting linguistic data from three DMs and most appropriate main dimension in proposed smart city model is obtained. This is smart transportation dimension.

In order to make a decision, it is necessary to examine all the main factors in the interior and the exterior. SWOT analysis is a systematic approach that supports decision-making and determines the most important internal and external factors. According to the smart transportation concept, SWOT factors of smart transportation in Istanbul are determined with literature review and expert opinions in second phase. HFL Analytic Hierarchy Process (AHP) method is used to define the final relative weights and priority factors. It is one of the significant methods for MCDM problems. This method is based on pairwise comparisons with hesitant judgments and gives the managers state control capability. Then, strategies are determined considering the most important of each SWOT factor. HFL Combinative Distance-based Assessment (CODAS) and HFL Complex Proportional Assessment (COPRAS) are MCDM method that evaluates the strategies in linguistic expressions in hesitate situation, determines their distances to the optimal solution, and selects the most appropriate strategy for smart trnasportation.

The objective of this study is to develop smart city model and propose strategic analysis of smart transportation using the HFL MCDM methods that will give a closer result to your daily life. This study will show how verbal information is effective for MCDM and how HFL methods which is a rare method in the literature, results in the case of hesitancy.

The main contribution of this thesis is the proposition of a new smart city model with quantitative basis in SWOT analysis with integrated HFL MCDM methods for smart transportation strategy selection for the first time. The proposed evaluation methodology as well as its application to a real case study has also contributions to the practical field by providing guidance to the managers who seek the most appropriate strategy for smart transportation.

ÖZET

Hızla büyüyen nüfus ve kırsal alanlardan kentsel alanlara göç, şehirlerin sorunları üzerinde önemli bir etkiye sahiptir. Bu sorunlar sadece şehirlerdeki ekonomik ve sosyal hayatı olumsuz yönde etkilemek ile kalmayıp aynı zamanda şehir sakinlerinin yaşam kalitesini de bozmaktadır. Nüfus artışı, kaynakların azlığı, yetersiz ve kötüleşen altyapı, enerji sıkıntısı ve fiyat istikrarsızlığı, küresel çevre kirliliği, insan sağlığı kaygıları gibi sorunlar daha iyi ekonomik ve sosyal fırsatlar için taleplerin artmasına sebep olmaktadır.

Akıllı şehir, yeni bir kavram olarak, ülkelerin politika metinlerinde, kentsel sorunların rasyonel çözümünde önemli potansiyele sahip bir yaklaşım olarak ön plana çıkmaktadır. Bu yaklaşım, kentsel varlıkların ve kaynakların bilgi teknolojileri kullanılarak entegre bir şekilde yönetilmesini sağlamaktadır. Son yıllarda karmaşık yaşam alanları ağında sosyal refah seviyesini artıracak akıllı şehirler geliştirmek için çalışmalar hızlandırılmıştır.

Ulaşım, altyapı ve ağların kendi kendine yönetilmesi ilkesine dayanan akıllı şehirler, birçok bileşenden oluşmaktadır. Verimli sonuçlar elde etmek ve başarılı olmak için şehir modellerinin oluşturulması çok önemlidir. Yeni bir oluşuma başlanırken var olan durumu analiz etmek ve ona uygun davranmak gerekmektedir. Bu yüksek lisans tezinde, ana boyut ve bileşenlerden oluşan kapsamlı bir akıllı şehir modeli sunularak bu modelin stratejik analizinin yapılması amaçlanmıştır. İki aşamadan oluşan çalışmada akıllı şehirlerin analizi yapılırken ve akıllı ulaşım stratejisi belirlenirken bilginin belirsiz olması durumunda kararsız bulanık çok kriterli karar verme (ÇKKV) yaklaşımı kullanılmaktadır.

Akıllı şehirler karma yapısı, çok çeşitli ve çelişkili kriterler içermesi sebebiyle değerlendirilmesi zor yapılardır. Bilginin belirsiz olması durumunda, akıllı şehirler ile ilgili karar vermek ve onları değerlendirmek de zorlaşmaktadır. Bu durumlarda, karar vericiler düşüncelerini sayılar ile ifade etmekte zorlanmaktadırlar çünkü bu niceliksel değerler günlük hayatta herhangi bir konu hakkında sahip oldukları kendi düşünce tarzlarından uzak kalmaktadır. Bu sayede, karar verici konumundaki uzmanlar fikirlerini dilsel ifadeler ile daha rahat ve net bir şekilde ifade edebilmekte ve böylece belirsizliğin üstesinden daha iyi gelinmektedir.

Çalışmanın ilk aşamasında, akıllı şehir bileşenlerinin önem dereceleri kararsız bulanık dilsel SAW (Simple Additive Weighting) yöntemi ile ağırlıklandırılmıştır. Ardından modelin ana boyutları ve bileşenleri arasındaki ilişki matrisi uzman görüşleri ile oluşturulmuş ve kararsız bulanık dilsel metot kullanılarak modelin en önemli olan boyutu "akıllı ulaşım" olarak belirlenmiştir.

Bir karar vermek için, iç ve dış tüm ana faktörleri incelemek gerekmektedir. SWOT (Strengths, Weaknesses, Opportunities, Threats) analizi, karar vermeyi destekleyen ve en önemli iç ve dış faktörleri belirleyen sistematik bir yaklaşımdır. İkinci aşamada, sunulan metodolojiyi uygulamak için vaka çalışması olarak İstanbul'da akıllı ulaşımın SWOT faktörleri belirlenmiştir. Faktörlerin önem derecelerini saptamak için kararsız bulanık dilsel Analitik Hiyerarşi Süreci (AHS) yöntemi kullanılmıştır. Bu yöntem, ikili karşılaştırmalara dayanmaktadır ve karar vericilere kontrol olanağı vermektedir. Daha sonra, en önemli SWOT faktörleri dikkate alınarak daha etkin bir akıllı ulaşım stratejisi belirlemek için kararsız bulanık dilsel CODAS (Combinative Distance-based Assessment) uygulanmış ve kararsız bulanık dilsel COPRAS (Complex Proportional Assessment) ile karşılaştırılmıştır.

Bu çalışmanın amacı, akıllı şehir çerçevesinde akıllı ulaşımın stratejik analizini günlük yaşantımıza daha yakın bir sonuçlar veren bir yaklaşım olan kararsız bulanık dilsel ÇKKV yöntemlerini kullanarak sunmaktır. Bu çalışma, sözel bilginin ÇKKV için nasıl etkili olduğunu göstermektedir.

Bu tezin ana katkısı, akıllı ulaşım stratejisi seçimi için kararsız bulanık dilsel ÇKKV yöntemleriyle entegre edilmiş SWOT analizinde niceliksel bir temel önermesidir. Gerçek bir vaka çalışmasına uygulanması ve önerilen değerlendirme metodolojisi akıllı ulaşım için en uygun stratejileri arayan yöneticilere rehberlik etmektedir.

1. INTRODUCTION

Today, cities have rapidly become urbanized places where crowded population is accumulating due to immigration. Rapid growth of the population, the shift of employment from agriculture to the industrial sector and services, and the sudden growth of cities caused an unhealthy and distorted urbanization. With the increase in population, scarcity of resources, inadequate and deteriorating infrastructure, energy shortages and price instability, global environmental splurge and human health concerns and demand for better economic opportunities and social benefits have begun to increase (Public Technology Platform, 2016). These difficulties not only affect the economic and social life in the cities negatively. It also deteriorates the life quality of the city inhabitants.

Smart city as a new concept has come to the forefront in the policy texts of countries as an approach that has a significant potential in the rational solution of urban problems. It is a vision of the development of urban space that expresses the integration of urban assets and resources by utilizing information technologies (Kass, 2017).

Cities are getting crowded, growing; technology is developing and becoming an integral part of our everyday life. In this process, demands of the citizens' increase, expectations become complicated. It is necessary to establish a strong model to realize the integration process in cities in the most favorable way. In this thesis, a comprehensive smart city model is presented by using literature review and expert opinions. In addition, this proposed smart city model is presented with hesitant fuzzy linguistic (HFL) multi-criteria decision-making (MCDM) approach.

Decision-making is defined as the choice between two or more options. When different decision options are available, not only one option always can be the best one. There is a better option that cannot be imagined, or real information that is not available at that time. In MCDM processes, the number of alternatives at the beginning of the number of solutions is clearly known (Yoon & Hwang, 1995).

Decision makers (DMs) are trying to make decision by combining different information. Sometimes DMs have difficulties to express their thoughts by numbers because these quantitative values are far from their realistic ways of thinking in daily life. However, it is difficult to decide when there are not sufficient criteria and information. When DMs evaluate alternatives, there is uncertainty and hesitancy in their opinions since the complex nature of the problem. Furthermore, DMs can more comfortably express their opinions with words, instead of crisp numbers. Therefore, hesitant fuzzy linguistic term sets (HFLTS) is used to reveal information in hesitate situations (Torra & Narukawa, 2009). HFLTS enables DMs to present easily their linguistic expressions during MCDM processes.

In particular, the hesitant fuzzy sets (HFS) have been used progressively for MCDM problems in recent years. Liu and Rodriguez (2014) made a new presentation of HFLTS with a fuzzy envelope to perform the computing with words process. Xu (2014) provides a comprehensive and systematic introduction to the hesitant fuzzy theory. He presented advanced methods about hesitant fuzzy preference relations, hesitant fuzzy aggregation techniques, hesitant fuzzy measures, hesitant fuzzy multi-attribute decision-making methods and hesitant fuzzy clustering algorithms.

The use of linguistic term sets with hesitancy has advantages in terms of ease of expression for DMs. First, DMs have the chance to express their ideas in linguistic expressions, not in numerical expressions in this decision model. There are many options for these linguistic expressions, on which the elasticity of the model is based. Moreover, this elasticity proposes the option to adapt the expressions of different criteria by their own nature. This is where the HFLTS becomes useful in solving this problem. Moreover, in this study, there are many factors to choose the most appropriate alternative. The MCDM based on HFLTS is used to give a more realistic result of the evaluation made by the DMs.

In this study, relationship matrix between main dimensions and components is constructed by collecting linguistic data from DMs and most appropriate main dimension in proposed smart city model is smart transportation.

In the transportation sector, continuous economic growth, continuous population growth and increasing urbanization have become decisive for the industry's future. The increase in population leads to an increase in mobility requirements for both passenger transport and freight transport. However, safe, punctual, shorter time and more comfortable transport demands have accelerated the development of transport. Within this framework, concepts such as the operation of transportation types supported by logistics services, the establishment of an efficient transportation infrastructure and the creation of the concept of sustainability that emphasizes safety in transportation types have emerged (T. C. Ministry of Transport, 2014).

The smart transportation in Istanbul currently does not fully utilize its potential because it is a newly developing field and it lacks strategic planning. This study aims to develop and evaluate the strategies for smart transportation in Istanbul, Turkey. This study presents strategic evaluations and suggestions on how to define Istanbul’s current situation in smart transportation and how to improve it to a more competitive level. Strategic evaluation of the smart transportation Istanbul is done through a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis (Hill & Westbrook, 1997). SWOT analysis evaluates the situation in smart transportation in a balanced way. Strategic recommendations are made by taking advantage of approaches to develop competitive strategies in the field of strategic management.

In 1960 and 1970, the SWOT analysis is presented by the American business and management consultant Albert S. Humphrey. Learned et al. (1969) described SWOT analysis, which later became an important tool that deals with complex strategic situations by presenting and organizing information in a clear way for decision making. At the same time, with this tool, the internal and external factors that are important to achieve organizational goals and objectives are also defined, so SWOT analysis evaluates the organization in terms of both internal and external environments. SWOT matrix aims to increase strengths, remove or reduce at the greatest extent the weaknesses, evaluate opportunities and identify threats (Dyson, 2004). SWOT factors are obtained using a qualitative framework, and there are many studies in the literature about this approach. Although the literature is rich in qualitative SWOT models proposed for smart transportation, it lacks a systematic, integrated and quantitative approach.

In this study, the importance degree of the smart city model components was taken from DMs and components are weighted by the HFL Simple Additive Weighting (SAW) method in the first phase. In the second phase, SWOT analysis integrated with HFL Analytic Hierarchy Process (AHP), HFL Combinative Distance-based Assessment (CODAS) and HFL Complex Proportional Assessment (COPRAS) is presented. The factors determined by the SWOT method are weighted with HFL AHP and the most appropriate strategy for smart transportation is selected with HFL CODAS and HFL COPRAS methods.

The objective of this study is to develop a new smart city model and propose staretegic analysis of smart transportation in smart city concept using the HFL MCDM methods, which will give a closer result to your daily life. This study will show how verbal information is effective for MCDM and how HFL methods which is a rare method in the literature, results in the case of hesitancy.

The main contribution of this thesis is the proposition of a quantitative basis in SWOT analysis with integrated HFL MCDM methods for smart transportation strategy selection for the first time. The proposed evaluation methodology as well as its application to a real case study has also contributions to the practical field by providing guidance to the managers who seek the most appropriate strategies for smart transportation.

The rest of this thesis is organized as follows. Section 2 provides basic concepts of smart city and its literature review. Subsequent section outlines basic concepts of smart transportation and its literature review. Section 4 explains basic concepts of hesitant fuzzy MCDM methods and their literature review. Section 5 presents the proposed evaluation framework with proposed methods; section 6 gives a case study to illustrate the robustness of the proposed approach. Conclusions and future research directions are delineated in the section 7.

2. SMART CITIES

2.1 Description and Development of Smart Cities

Urbanization rate in Turkey is above the world average. Researches show that 54% of the population lives in urban areas in the 20th century and 4 out of every 5 people will live in cities in the next 40 years. Urbanization rate will reach 70-75 percent in Turkey. The population of Istanbul has reached one million in 1896, 300 years after its foundation. The population within the borders of the municipality has increased 8 times in 100 years since this date and reached 8 million. Over the past 15 years, more than 5 million people have been added to the Istanbul population. Istanbul, one of the most crowded cities in Europe, continues to grow. Istanbul is growing up with years of accumulated smart city transformation. At present, the growing city Istanbul is a smart city transformation period (Karpat, 2003).

Smart cities do not form suddenly, but they develop with years of accumulation. In the historical development process, cities had different characteristics and metrics. As seen in Figure 2.1, cities have developed over the years influenced by different innovations and now the last stage is the smart city (Karadağ, 2013).

Figure 2.1: Stages of Cities

The pre-industrial cities remained mostly a minority, and they have undergone very little transformation in terms of structure and functionality until industrialization. Few of the pre-industrial cities have populations exceeding 10,000. These are religious and administrative cities and their economic functions remain on the second plan. In these cities, administration, religion and education are dominated by the upper classes. In addition, technology and economic organizations are primitive (Keleş, 2012).

With the industrial revolution, post-industrial cities became more important than pre-industrial cities. In these cities, the living and working areas are separated by certain lines. In these cities, specialization and division of labor are observed at a high level. At the same time, social mobility with industrial cities has improved further. The working class has emerged and the population of the cities has increased rapidly due to the need for more workers (Keleş, 2012).

The cities with a population of over one million have been called metropolitan cities. The great development that has taken place with the industrial revolution has also caused qualitative and quantitative transformation and change in cities. Because of this change process, a "metropolitan city" structure emerged from traditional cities (Çamur & Yenigul, 2009).

Global cities are the places where information, communication, communication, cultural interaction, capital transcends national boundaries and gain international qualifications. They are cities that have increased dependency on many levels such as economy, culture, politics and governance (Kleniewski & Thomas, 2011).

Digital cities are cities that have a flexible and service-oriented computing infrastructure based on open industry standards that combine the infrastructures of broadband communications technologies. Thanks to digital technologies and a large area of infrastructure, networks, city-based organizations, social groups and entrepreneurs are interconnected (Li et al., 2013).

All cities have passed these stages. The current stage is smart cities. In the process of development, cities move from early maturity stages to full maturity stages. The maturity model is used to assess the current maturity level and set targets for the desired maturity level.

The most obvious characteristic of the age that we are in is the rapid change. The formation of societies that can keep up with the rapid changes of the age is directly related to the sustainable and high welfare-level environments. In recent years, many countries have begun to build urban infrastructures and services to raise the welfare level of communities and to manage growth and development in a sustainable way.

Rapid population growth seen in Turkey as well as in all countries, urbanization, global climate change, increasing ecological footprint and consumption elements have brought along living environments that are contrary to human nature and environmental deformation. With the increase in population, scarcity of resources, inadequate and deteriorating infrastructure, energy shortages and price instability, global environmental splurge and human health concerns and demand for better economic opportunities and social benefits have begun to increase (Washburn et al., 2009). These problems not only affect the economic and social life in the cities negatively but also it decreases the life quality of the city inhabitants and the competition power of the cities (Kass, 2017). Reducing these negative incidences that come with urbanization is closely related to the more efficient management of the existing systems in the cities. At this point, smart cities have come to the forefront in the policy texts of countries and international organizations as an approach that has a significant potential in the rational solution of urban problems.

When it was looked at the existing literature and applications, it can be seen very different definitions of "Smart City". Some of these definitions are as follows:

- For the construction of smart cities, there are four critical elements (Smart Cities Project Guide, 2010):
  - ➢ Economic, social and environmental sustainability and leadership that will inspire them,

- ➢ Industry and city collaborations, which include both governments and citizens,
- ➢ To build cities which use less resource, with ideas and solutions based on leverage impact
- ➢ To strengthen the social capital of the city with individuals who have a conscious digital society view.

- According to another definition, smart city is a city that invests in people and social capital, has modern transportation and communication infrastructure, sustainable economic growth and high quality of life, and governs natural resources through participatory governance (Caragliu et al., 2011).
- The smart city has the highest level of services and services offered to citizens and plans the preventive maintenance activities using the best resources of the city by monitoring the situation of all major infrastructure (roads, bridges, tunnels, railways, metro lines, communication, water, energy, buildings) and integrating systems (Chourabi et al., 2012).
- The smart city is a vision of development of urban that expresses the integration of urban assets and resources by safely utilizing information technologies (Public Technology Platform, 2016). According to the Public Technology Platform Report (2016), the following concepts stand out for the definition of smart city:
  - ➢ Making urban applications compatible with digital technologies,
  - ➢ Connecting applications with digital platforms,
  - ➢ Governance - managing the city with the people,
  - ➢ Effective use of energy resources,
  - ➢ Effective use of water resources,
  - ➢ Nature and harmony with people,
  - ➢ Intelligence of buildings, infrastructure and transportation,
  - ➢ Sustainable asset management,
  - ➢ Faster adaptation to changing conditions.
- A smart city is an integrated system in which human and social capital interacts, using technology-based solutions. It aims to achieve efficiently sustainable and resilient development and a high quality of life addressing urban challenges based on a multi stakeholder, municipality based partnership (ASCIMER, 2017).

Considering that these definitions, smart cities are based on the idea of restructuring cities to maximize efficiency for people and nature. Smart cities with a human-focused, strategic, environment-friendly management approach, service areas and living standards are developed city structures. These structures are based on using innovative and sustainable methods to create new living spaces that are resource efficient and smartly consumed, respectful to nature, comfortable, healthy, citizen-focused (Hollands, 2008). From these definitions, the components that should be basically contained in the smart cities are shown in Figure 2.2.

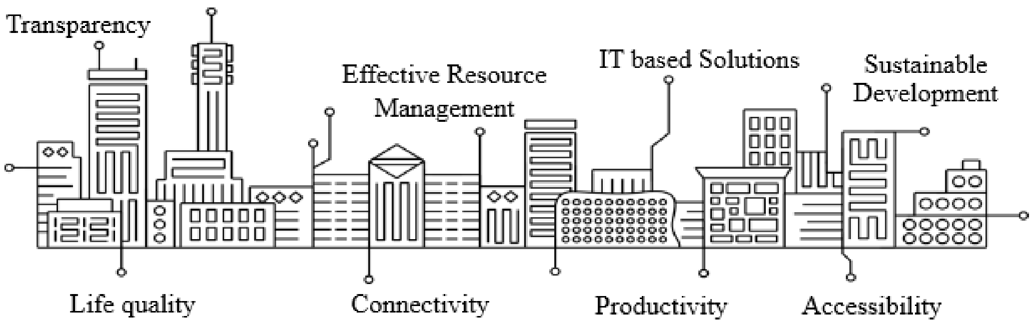

Figure 2.2: Smart City Concept

Smart City is the newest urban concept that connects the different resources of a city using advanced Information and Communication Technologies and Internet of Things (IoT). Information and Communication Technologies can be connected with city infrastructure and enabled the authorities to monitor the various ongoing activities across the city. IoT sensors collect data from citizens and devices by providing integration with real-time monitoring systems. This data can be developed and analyzed to identify problems around the city. Thus, governments and municipalities help people take steps to improve their lives (Nam & Pardo, 2011).

Smart city investments are often expensive technology investments. The ability to generate the targeted effect of spent money depends on effective management at every stage of a good planning and transformation journey. It is essential that the cities is well-defined in smart city transformation process, proceed with a inclusionary vision and strategies, and take action by planning the targeted effect for the city. Within the scope of this study, it was emphasized that smart cities need a holistic perspective instead of technological solutions and a smart city model.

2.2 Main Problems of Cities and Smart Solutions

The focal point of cities is to meet the needs of citizens. There are some problems to meet these needs. It is possible to collect these main problems under seven sub-headings (see Figure 2.3). Potential problems that smart cities are expected to solve are as follows (Public Technology Platform, 2016; ARUP, 2013):

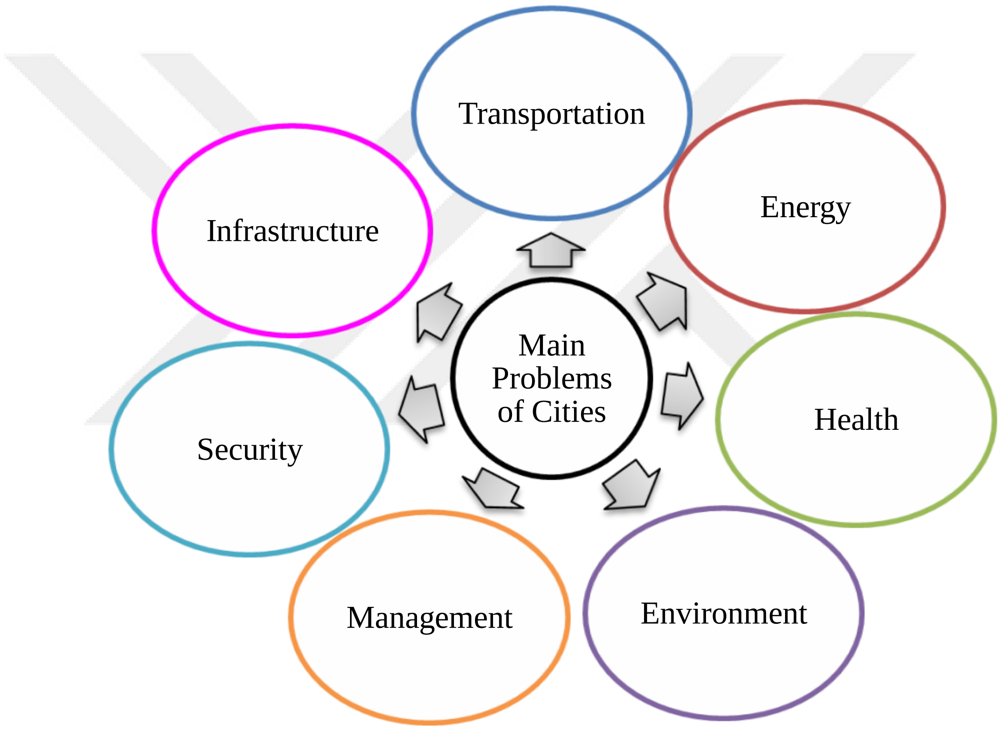

Figure 2.3: Main Problems of Cities

Transportation (Civitas, 2015; BVRLA, 2016):

- Inadequate transportation infrastructure for the number of vehicles along with the increasing population
- Increase in traffic time
- Increase in transportation costs
- Increase in harmful exhaust gas emission
- Life and property losses as a result of traffic accidents

Energy (Forrester, 2010; Gouveia et al., 2016):

- The use of more expensive and inefficient energy resources with increased energy demand
- Lost and illegal electricity usage in distribution

Health (Giffinger & Pichler-Milanović, 2007):

- Delays in on-site and on-time emergency interventions due to problems caused by transportation
- Due to the population density, the control of epidemic diseases in cities is getting harder
- The environmental impacts of urban life negatively affect public health

Environment (Forrester, 2010; Deloitte Report, 2016):

- Rapidly consuming renewable resources
- Environmental threats such as air and water pollution for urban life
- Irregular and unplanned urbanization
- Solid waste collection and storage problems

Management (Anthopoulos, 2015; ASCIMER, 2017):

- Difficulty in providing services for local and central governments with increasing population
- Declining life quality because of the quality of services

Security (Deloitte Report, 2016):

- Increase in crime rates in cities
- No timely preventive solutions for increased security problems
- Slow-running security and access control systems

Infrastructure (Council, 2013):

- Buildings that use more energy than necessary
- Infrastructure systems that do not have the key competencies to assess and understand technology risks, technology change rate and life cycle

- Infrastructure systems lacking from technology

Today, solutions aimed at solving the problems of the cities and increasing the quality of life of citizens gain importance and are rapidly applied in many cities around the world. Smart city is a design that facilitates life with digital designs and provides electronic information and guidance with e-services. Sustainable, ecologically protected, environmentally friendly urban cities that use renewable energy and have unobstructed and planned transportation, high green area, green buildings are being designed with smart city solutions. These smart solutions can be made under such dimensions (see Figure 2.4) as planning, re-structure, system operators, information technology investments, citizen participation and data sharing (Council, 2013).

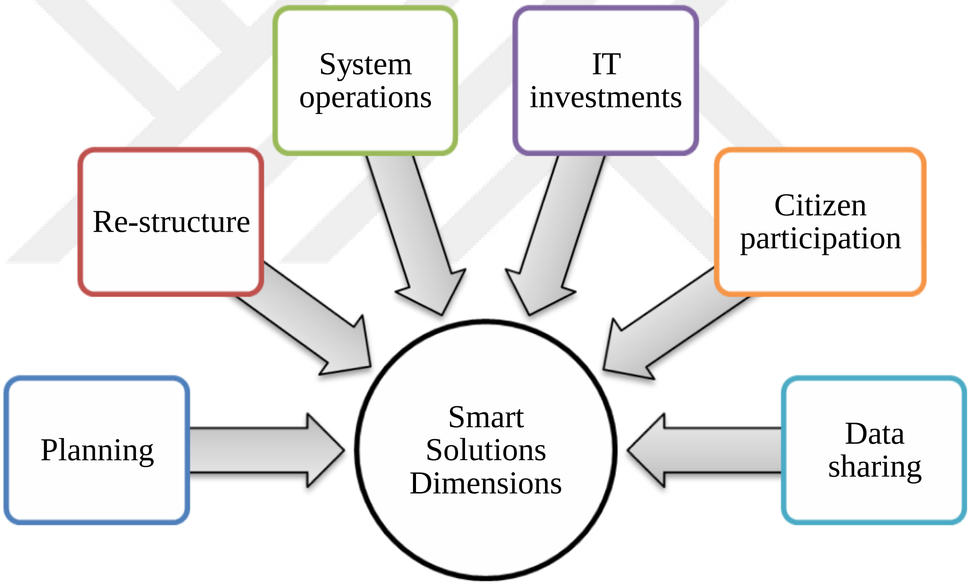

Figure 2.4: Smart Solutions Dimensions

There are some smart solutions to meet the needs of citizens. Street lamps that used to illuminate public spaces can control air pollution and provide wireless internet connection. The quantity and quality of water can be analyzed by hydrological cycle steps, especially for agricultural and industrial use. With the wireless receiver networks, the conditions of agricultural crop fields can be tracked and cultivation processes can be managed. By combining humidity, temperature and light receivers, the risks of frost or plant diseases can be reduced; irrigation needs can be optimally regulated. Information is provided before or during travel, using dynamic and multi-mode information systems to enhance traffic and transport efficiency and the quality of the transportation experience (Deloitte Report, 2015).

Some of the smart solution technologies that are ready to use within these dimensions are: Geographic Information System, Urban Digital Maps, Transportation Information System, Smart Signaling Systems, Smart Metering Systems, Fast Internet Infrastructure, Wireless Internet Infrastructure 3G - 4G GSM Technology, Smart Building Architecture, Citizen Address and Population Information System and Waste Management System (Alkan, 2015).

2.3 Benefits of Smart Cities Approach

Smart cities evaluate the environment in the best way, protect it, purify its own waste and even produce some of its energy with renewable energy sources. By making a city suitable for the definition of a smart city, the number of people who want to live in that city will increase. However, in smart cities, people will be able to benefit more from cultural and touristic activities. Many financial institutions and commercial companies will start to take place in these cities where the infrastructure is completed and the city IT system works perfectly. Thus, the brand value of smart cities will increase, so smart cities will clearly be ahead of normal cities (Green, 2011).

Smart cities integrated with innovations have many benefits. These benefits include safety, tourism and leisure, retail and logistics, healthcare, government, people, mobility, energy, water and waste (Deloitte Report, 2015).

- For safety, it responds quickly to public safety threats by analyzing the data of sensors and cameras in real time.
- For tourism and leisure, by analyzing tourist movements and real-time incentives, it helps tourists to move more easily.
- For retail and logistics, it ensures that products and services are exchanged in a peer-to-peer communication model.

- For healthcare, in high-volume patient data, artificial intelligence provides better diagnosis and personalized treatment. Persons in need of care can live longer at home, thanks to the advanced warning system and health care robotics.
- For government, identification of policies in the light of data provides measurable evidence of effectiveness. In decision-making processes, co-production provides new forms of digital democracy and participatory management.
- For people, dynamic citizen groups organize themselves and work towards their common interests.
- For mobility, optimal use of the transportation infrastructure (roads, parking places) results in lower levels of congestion and pollution.
- For energy and environment, energy saving is achieved through real-time inspections of energy usage and combining them with concepts. To adjust energy demand, household appliances respond to dynamic energy costs. The wastes are collected more efficiently by the sensors in the waste containers. The analysis of the data provided by the sensors in the water supply network allows the leak and quick repair.

According to ARUP's Report (2013) for smart city solutions, the benefits of smart cities are as in Figure 2.5.

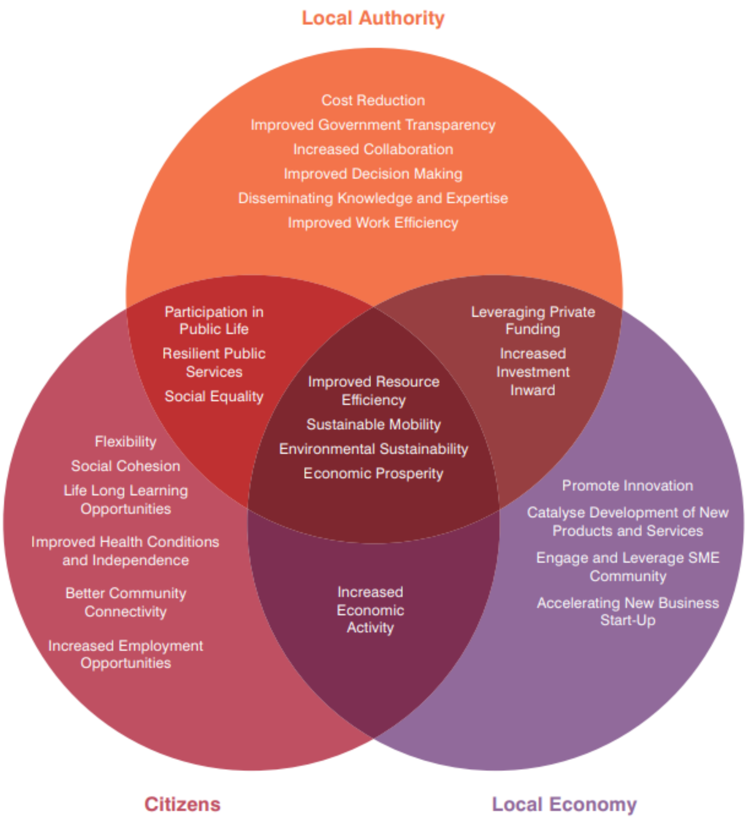

Figure 2.5: Benefits of Smart Cities

2.4 Literature Review of Smart Cities

There are many studies in the literature about smart cities, one of the popular topics of recent times. In this study, the literature review of smart cities was done in two stages. In the first stage, studies of smart cities with analytical techniques were presented. In the second stage, the literature review of smart city models was presented by examining both academic studies and industrial reports.

2.4.1 Literature Review of Smart Cities with MCDM

In the literature, studies about smart city generally focus on smart city definitions, methodology. For these studies, you can examine literature review studies (Cocchia, 2014; Anthopoulos, 2015). Recently there has also been an increase in the number of studies on smart cities and their application areas. In this study, smart cities are used together with analytical techniques. As a result, studies involving the use of smart cities and MCDM methods are given in Table 2.1.

Table 2.1: Studies of Smart City with MCDM Methods

Author(Year)	Aim of the Study	Methods	Application Area
Lombardi et al. (2012)	to offer a profound analysis of the interrelations between smart city components	ANP	-
Kourtit et al. (2014)	to analyze the performance of global cities	PROMETHEE	40 global cities
Anthopoulos & Fitsilis (2015)	to identify social networks in smart cities	ELECTRE I - ELECTRE TRI	-
Shinde & Kiran (2016)	to focuse on survey of various auction mechanisms proposed for cloud market	AHP	-
Gouveia et al. (2016)	to present an innovative analytical framework of the energy system in smart cities	PROMETHEE	Évora (Portugal), Cesena (Italy), Nottingham (United Kingdom) and Trikala (Greece)
Anthopoulos & Giannakidis (2016)	to propose the Task-Based Modelling method and policy making process standardization for smart cities	PROMETHEE	Trikala, Greece
Nathanail et al. (2016)	to present the evaluation framework for smart city solutions	AHP	-
Coelho et al. (2017)	to present multi-objective power dispatching in smart cities	Mathematical programming based heuristic	-
Anand et al. (2017)	to determine the importance of various criteria for sustainability in a smart city	fuzzy AHP - DEA	India
Giang et al. (2017)	to present the suitable methodology for modelling a Living Lab decision- making process in Smart City projects	fuzzy cognitive map	-
Rad et al. (2017)	to develop a methodological framework for assessment of smart cities	ANP-DEMATEL	Tehran, Iran and Seoul, South Korea
Carli et al. (2017)	to develop a MCDM for energy efficiency optimization of street lighting in smart cities	TOPSIS	Bari, Italy
Jain et al. (2017)	to propose wireless sensor network-IoT paradigm for smart cities	TOPSIS	-
Kurniawan et al. (2017)	to present smart city operation center priority optimization	fuzzy MCDM	Makassar, Indonesia

Looking at the table, the smart city concept has been used with many MCDM methods such as AHP, ANP, TOPSIS, PROMETHEE, ELECTRE and DEMATEL etc. Its use with advanced MCDM methods such as fuzzy is very limited. In this study, this subject will be used in conjunction with the hesitant fuzzy linguistic MCDM, which is a missing part of the literature.

2.4.2 Literature Review of Smart City Models

Cities are getting crowded, growing; technology is developing and becoming an integral part of our everyday life. In this process, the demands of the citizen increase, expectations become complicated. Our lives are in great change with technology, and city governments need more than ever to think about tomorrow. It is necessary to establish a strong model to realize the integration process in cities in the most favorable way (Deloitte Report, 2015). With a smart city model built in a comprehensive way, planning and applications can be done easily. For this reason, there are many smart city models that are recommended in the literature and industry. Some of these models are included under this title.

The smart city models with their dimensions presented in the literature are given in Table 2.2. Looking at the table it is possible to see that the models have been diversified. Different dimensions are combined with different components. Some studies have a theoretical approach while others have an application area.

One of the most prominent models in the literature is Cohen's (2013) Smart City Wheel in Figure 2.6.

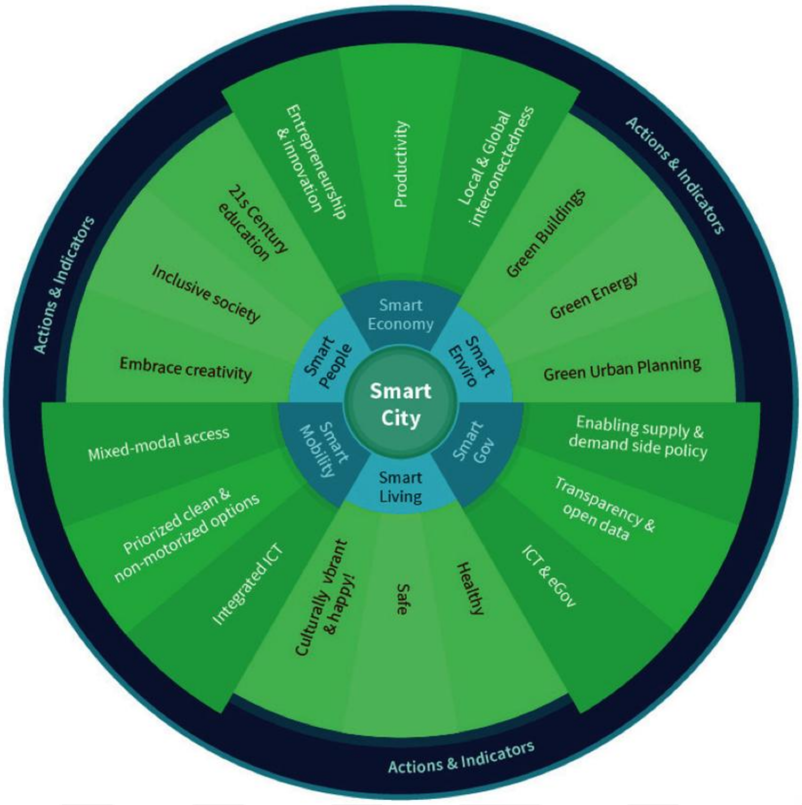

Figure 2.6: Smart City Wheel (Cohen, 2013)

Hsieh et al. (2011) presented a smart city model, which includes dimensions of smart environment, smart transportation, smart lifestyle, and smart economy for smart city development strategies. Lazaroiu & Roscia (2012) presented a detailed smart city model included dimensions and components and applied this model for 10 smart cities. Lee et al. (2014) proposed case framework for smart city analysis with smart city model, which include six dimensions and applied in San Francisco and Seoul. Dall'O et al. (2017) developed a methodology for assessing smartness through indicators that is applicable to small and medium-size cities. Fernandez-Anez et al. (2017) proposed an integrated conceptual smart city model in the case of the Vienna Smart City strategy. Shi et al. (2018) proposed a comparison of Chinese smart city evaluation models.

In theoric papers, only new smart city model with dimensions and components is proposed. In theoric and application papers, a new smart city model is proposed and this model is applied in a country or city. There is only one model for cities in Turkey are proposed in the literature. This model was applied for Ankara. In this study, the proposed smart city model will be applied for Istanbul.

Table 2.2a: Smart City Models

Author (Year)	Dimensions	Components	Theoric/ Theoric and Application	Application Area
Hsieh et al. (2011)	Smart environment Smart transportation Smart lifestyle Smart economy	-	Theoric and Application	Chung Hsing, Taiwan
Nam & Pardo (2011)	Technology People Community	6 components 4 components 2 components	Theoric	-
Lombardi et al. (2012)	Smart governance Smart economy Smart human capital Smart living Smart environment	60 indicators classified in the 5 clusters	Theoric	-
Lazaroiu & Roscia (2012)	Smart economy Smart mobility Smart environment Smart people Smart living Smart governance	7 components 4 components 4 components 7 components 7 components 4 components	Theoric and Application	Pavia, Bergamo, Como, Salerno, Cremona, Rome, Rieti, Naples, Foggia, Milan
Chourabi et al. (2012)	Management and organization Technology Governance Policy People and communities Economy Built infrastructure Natural environment	- 2 components 8 components - 7 components - 3 components -	Theoric	-
Cohen (2013)	Smart economy Smart mobility Smart environment Smart people Smart living Smart governance	3 components 3 components 3 components 3 components 3 components 3 components	Theoric	-
Lee et al. (2014)	Urban openness Service innovation Partnerships formation Urban proactiveness Smart city infrastructure integration Smart city governance	2 components 2 components 2 components 2 components 3 components 6 components	Theoric and Application	San Francisco - Seoul

Table 2.2b: Smart City Models

Author (Year)	Dimensions	Components	Theoric/ Theoric and Application	Application Area
Neirotti et al. (2014)	Natural resources and energy Transport and mobility Buildings Living Government Economy and people	6 components 3 components 3 components 8 components 4 components 4 components	Theoric	-
Mattoni et al. (2015)	Energy Economy Mobility Environment Community	-	Theoric	-
Dall'O et al. (2017)	Smart economy Smart energy Smart environment Smart living Smart people Smart mobility Smart governance	-	Theoric and Application	Northern Italy
Varol (2017)	Smart governance Smart living Smart environment Smart mobility	5 components 3 components 6 components 5 components	Theoric and Application	Ankara, Turkey
Uçar et al. (2017)	Smart economy Smart mobility Smart governance Smart people Smart living Smart environment	-	Theoric and Application	Amsterdam
Fernandez-Anez et al. (2017)	Smart economy Smart mobility Smart environment Smart people Smart living Smart governance	-	Theoric and Application	Vienna
Rondini et al. (2017)	Smart mobility Smart environment Smart people Smart living Smart governance smart economy	4 components 2 components 1 component 1 component 1 component 1 component	Theoric and Application	Bergamo, Italy
Shi et al. (2018)	Smart individual Smart management Smart service Smart economy Smart guarantee Smart infrastructure	2 components 3 components 2 components 3 components 3 components 3 components	Theoric and Application	China

Table 2.2c: Smart City Models

Author (Year)	Dimensions	Components	Theoric/ Theoric and Application	Application Area
Alabdulatif et al. (2018)	Smart grid Smart home Smart community Smart environmental monitoring Smart factory Smart energy Smart trafic and logistics Smart healthcare	-	Theoric	-

The smart city models with their dimensions presented in the industrial reports are given in Table 2.3. Looking at the table, it can be said that the models are generally different from each other although there are common points.

Table 2.3a: Smart City Models – Industrial Reports

Model Name	Institution/Source (Year)	Dimensions	Components
Characteristics of a smart city	Giffinger & Pichler-Milanović (2007)	Smart economy Smart mobility Smart governance Smart people Smart living Smart environment	7 components 4 components 4 components 7 components 7 components 4 components
Smart City Blueprint	FORRESTER (2010)	City administration Education Healthcare Public safety Real estate Transportation Utilities	1 component 3 components 2 components 1 component 3 components 1 component 1 component
Smart Cities	Deloitte (2015)	Smart mobility Smart safety Smart finance Smart education Smart government Smart energy, water & waste Smart retail & logistics Smart tourism & leisure Smart buildings & living Smart manufacturing Smart health	-

Table 2.3b: Smart City Models – Industrial Reports

Model Name	Institution/Source (Year)	Dimensions	Components
Smart City Indicators	IESE Cities in Motion Index (2016)	Human capital	7 components
		Social cohesion	7 components
		Economy	7 components
		Public management	6 components
		Governance	5 components
		Environment	8 components
		Mobility and transportation	7 components
		Urban planning	5 components
		International outreach	5 components
		Technology	9 components
Smart City Key Themes	United Nations Commission on Science and Technology for Development (2016)	Smart economy	6 components
		Smart mobility	5 components
		Smart governance	6 components
		Smart people	5 components
		Smart living	5 components
		Smart environment	4 components
Smart City Mission	Ministry of Housing and Urban Affairs, Government of India (2016)	E-governance and citizen services	5 components
		Energy management	3 components
		Waste management	4 components
		Water management	3 components
		Urban mobility	3 components
		E-medicine	-
		Skill Development	-
Smart City Model	Public Technology Platform (2016)	Smart economy	6 components
		Smart mobility	3 components
		Smart governance	3 components
		Smart people	6 components
		Smart living	6 components
		Smart environment	4 components
Smart Cities Index	EasyPark Group (2017)	Transport and mobility	4 components
		Sustainability	4 components
		Governance	4 components
		Innovation economy	1 component
		Digitalization	4 components
		Living standard	1 component
		Expert perception	1 component
Smart City Model	Urban-Hub (2017)	Safety	2 components
		Mobility	3 components
		Real-time democracy	2 components
		Homes-security and Automation	3 components
		Vehicles	2 components
		Office buildings	2 components

Table 2.3c: Smart City Models – Industrial Reports

Model Name	Institution/Source (Year)	Dimensions	Components
Smart City Project Actions	ASCIMER (2017)	Smart economy	5 components
		Smart mobility	7 components
		Smart governance	4 components
		Smart people	5 components
		Smart living	7 components
		Smart environment	6 components

Giffinger and Pichler-Milanović (2007) proposed a smart city model for ranking of European medium-sized cities. In this model, there are 6 main dimensions of smart city. These are smart economy, smart mobility, smart governance, smart people, smart living and smart environment. Smart economy includes factors as innovation spirit, entrepreneurship, economic image & trademarks, productivity, flexibility of the labor market, international embeddedness and ability to transform. Smart People dimension is not only described by the level of qualification or education of the citizens but also by the quality of social interactions regarding integration and public life and the openness towards the “outer” world etc. The other components are as in Figure 2.7.

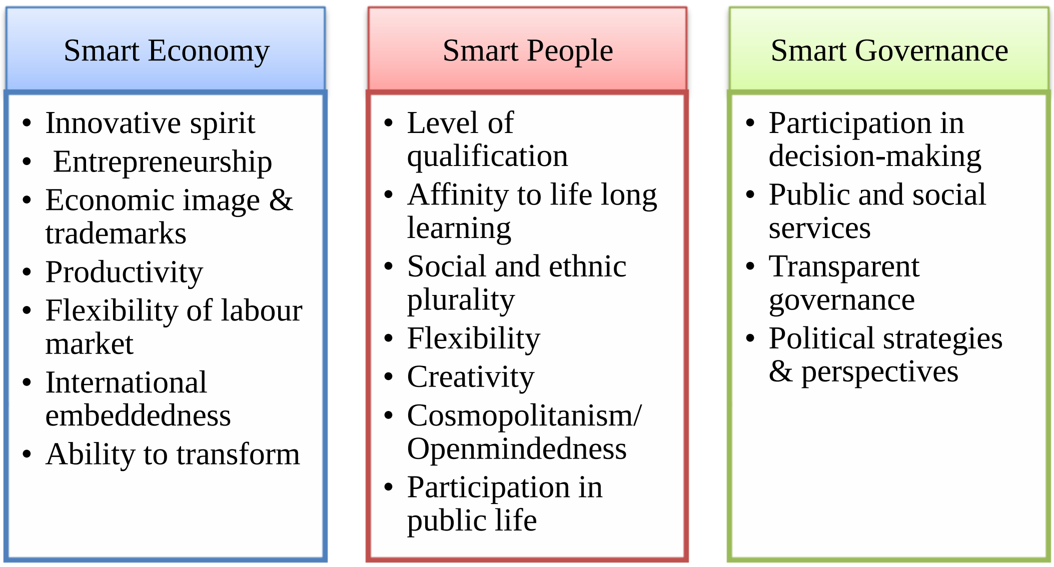

Figure 2.7a: Smart City Model - Giffinger and Pichler-Milanović (2007)

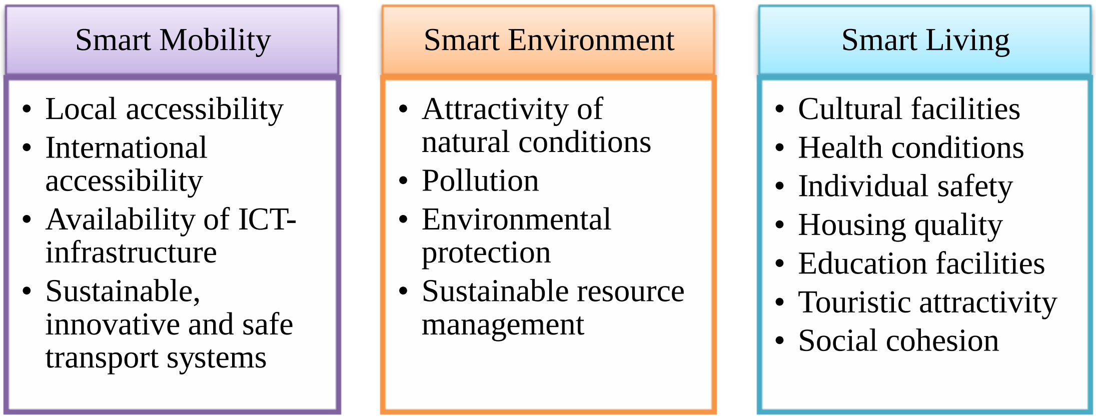

Figure 2.7b: Smart City Model - Giffinger and Pichler-Milanović (2007)

In the Deloitte Report (2015), the main dimensions of the smart city model are presented with goals and challenges as in Figure 2.8. In report, it is emphasized that smart city models come into being with intelligent solutions created against the difficulties.

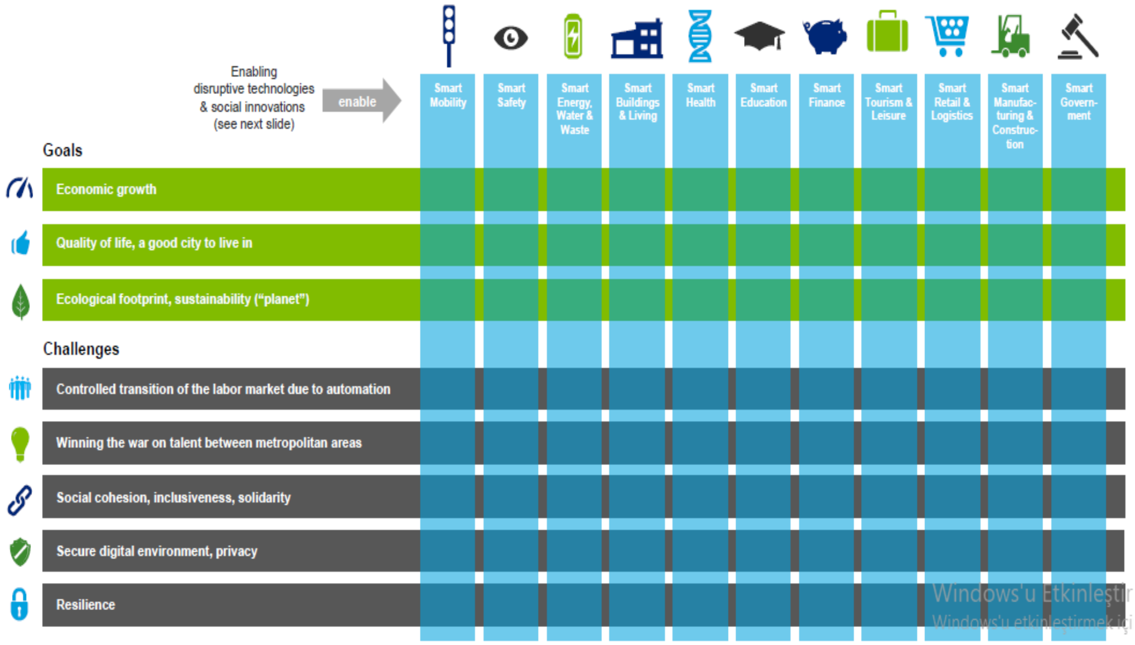

Figure 2.8: Smart City Model – Deloitte (2015)

Ministry of Housing and Urban Affairs, Government of India (2016) has created a smart city project to prevent the problems because of increasing population. For this reason, they have created a smart city model. This model includes adequate water supply, assured electricity supply, sanitation, including solid waste management, efficient urban mobility and public transport, affordable housing, especially for the poor, robust IT connectivity and digitalization, good governance, especially e-Governance and citizen participation, sustainable environment, safety and security of citizens, particularly women, children and the elderly, and health and education. Illustrative model is in Figure 2.9.

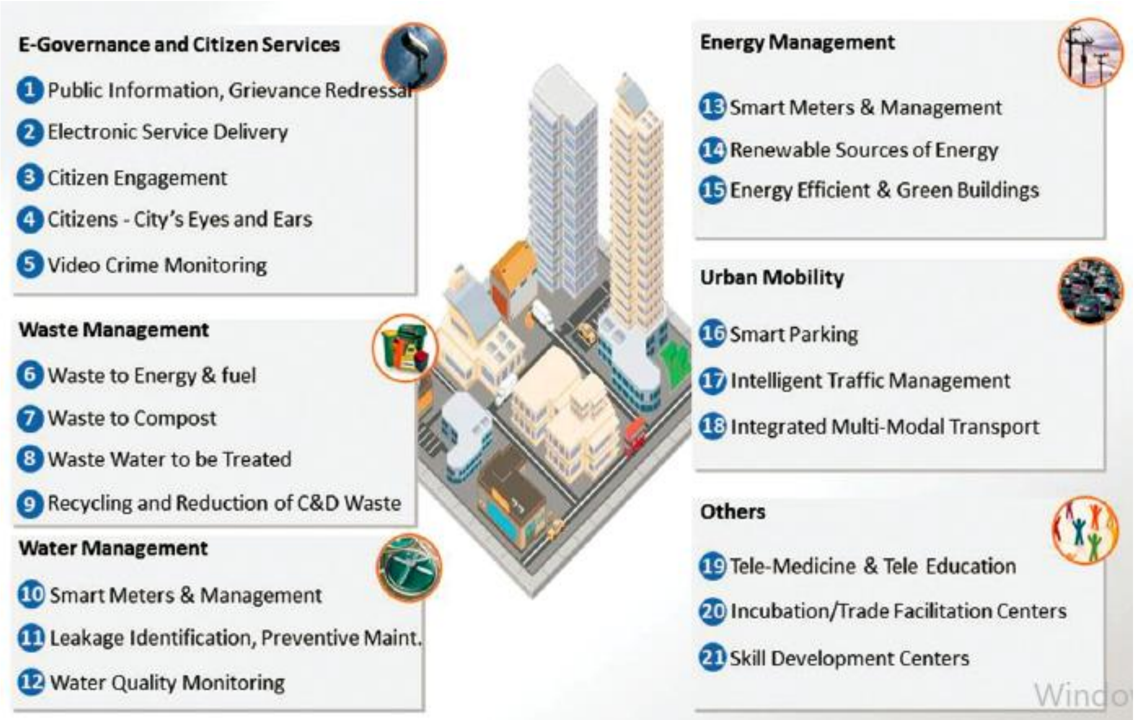

Figure 2.9: Smart City Model – Government of India (2016)

With all these studies and expert opinions examined, a model for the smart city has been created and it will be explained in the following sections.

2.5 Smart City Examples in Turkey

From the perspective of urbanization, the smart city approach is an integrated approach to aim at increasing the quality of life of citizens on the urban scale of information and communication technologies. Increasing the efficiency of urban systems (especially transportation and energy); improvement in living areas (reduction of air and noise pollution etc.); improvement in services offered to citizens; and the development of local economies and the increasing competitiveness of cities are among the basic objectives of smart applications.

The use of technology as a tool to increase the quality of life; cooperation between institutions; knowledge and experience-based planning; and involvement of the citizen in the planning and implementation processes are important for the achievement of smart city applications. It is also important for city administrators to closely monitor these developments and analyze their assimilation and transition reasons in transition applications to smart cities that are beginning to become a priority trend in all countries.

Smart city applications in our country are mostly focused on citizen's application and integration of urban IT systems. Some of these applications are MIS (Management Information System), GIS (Geographic Information System), mobile applications and citizen-focused interactive applications etc. The number of communication channels is increased with e-municipality, city guide, tele-municipality, mobile municipality, electronic signature, etc. to access the municipality from any platform independently from time and space and to get service (Green, 2011).

The first application launched in Yalova, Turkey in early 2000, is the establishment of an eco-tech residential project location called Informatics Valley Project. Informatics Valley Projects were later taken up by Bursa, Kocaeli, Ankara and other cities.

There are some smart applications in Antalya (Public Technology Platform, 2016). With the free Wi-Fi service, independent access was provided to the citizens. With the Panic Button distributed to the citizens, by pressing the button in the emergency case provided the convenience of both calling an ambulance and informing their relatives.

With Chronic Patient Monitoring, it is ensured that the glucose, blood pressure and pulse values of chronic patients are measured and monitored centrally.

Another service realized is the City Information Kiosks. These devices, which are offered to the use of domestic and foreign tourists and the citizens, show the information about the city in this screen. Kiosks form a bridge between the municipality and citizens in order to enable citizens to access institutional services without reaching the service building. Access to the services has been facilitated by placing kiosks at the point-of-sale service buildings, interurban bus terminal, airport domestic and international terminals where the city center is intensely active.

The smart applications implemented in Izmir are Geographical Address Information System, Izmir 2 and 3 Dimensional City Guides, Geographical Cemetery Information System, Reconstruction Information System, and Vehicle Tracking System and free Wi-Fi Services (Ilıcalı et al., 2016).

The smart applications implemented in Bursa are Iris and Fingerprint Recognition System, Fire Resistant Steel Doors and Cabinets, Corridor and Indoor Camera Monitoring, Backed Air Conditioning System, Automatic Fire Detection System, Automatic Fire Fighting System, Secure Public Wireless Internet, BUSMEK Online Registration, BUMEP Online Registration, BENMEP Online Registration, Orchestra Online Registration and E-Declaration etc. (Karadağ, 2013).

However, apart from project definition, in some of the district municipalities in Istanbul, smart city applications have been taken into consideration in the form of a project design (Alkan, 2015).

Fatih and Beyoğlu Municipalities have implemented three-dimensional street images that work in harmony with the Google Earth program. Fatih Municipality also incorporates Augmented Reality application into Smart City projects. According to this application, when the image of any building in Fatih Municipality is photographed and sent to the relevant service center via 3G - 4G communication technology, the existing information about that building can be transferred to the user immediately from the information center (T. C. Ministry of Development, 2014).

Beşiktaş Municipality CRM system (End-to-End and Notification Management from All Channels) is the only system that follows and the solution in all units, not only in the call center or service desk, but also in requests and complaints from all channels. At this point, notifications from all communication channels such as mobile, call center, social media, etc. are collected in a single pool, routed to the sections as designed, and the process runs until the flow is resolved. The escalation system operates in case of delay. The correct operation of the process starts with the correct categorization of the citizen in the process of the request. Then, the corresponding workflow starts according to the specified category. Units and people take part in the solution process. With this new structure, not only the call center but also all the units and directorates can be managed in a single common platform for the analysis of citizen demands.

Social Alert Service was launched in Beşiktaş for 75 years of age and above, living alone or in a disadvantaged position, in order to ensure that urban citizens can easily benefit from health support services and to increase the quality and duration of life. This service enables citizens to reach health and social support services easily and quickly through an electronic system. There are three buttons on the Social Alarm Device that works with an electronic system and that is placed in the house and connected to the telephone line. With these buttons, emergency calls can be made by voice and continuous communication without the use of a handset by a citizen in cases like home accidents, health problems etc. They can request meal, housekeeping service, hairdresser service in home, practical house arrangements, locksmith service, and medical consultation on the phone, doctor's examination at home, nurse and patient care services, patient transport ambulance, psychologist and dietician services. It is easy to communicate without having to enter a number with the relatives previously saved in the device. The smart city applications used in the municipalities of Istanbul are summarized as Table 2.4 (T. C. Ministry of Development, 2014).

Table 2.4: Smart City Applications in Municipalities

Energy	• Smart Street Lighting Systems • Buildings Energy Management Systems • Smart Electricity Meters • Smart Electricity Network
Water	• Smart Water Meters and Demand Management • Leak Detection and Preventive Maintenance
Transportation	• Smart Parking Meters and Pricing • Fleet Tracking, Maintenance, Positioning Services • Integrated Transit Payment
Urban services	• Culture and Tourism Services • Access to Services From Electronic Channels • Emergency Response and Disaster Services • Air Quality Follows

In this study, the city that will be covered within the scope of the smart city is Istanbul. Because, it is a bigger metropolitan than other cities, and at the same time, the work done within the scope of a smart city is at a higher level in Istanbul. The details will be explained in the following sections.

3. SMART TRANSPORTATION

3.1 Description and Development of Smart Transportation

Smart transportation in general can be defined as transportation solutions designed to alleviate the thinking or decision-making burden on people. From this point of view, the first smart transportation application is traffic lights with electric that were first used in 1928. With the traffic lights, problems such as the priorities of the vehicles and the pedestrians of the highways, passing times, etc. have been resolved. Thus, traffic lights take on the task of thinking and deciding of the pedestrians and drivers. Today, smart transportation refers to systems based on the use of electronic and computer technology in transportation regulation and management (Civitas, 2015).

Each of the three leading countries of intelligent transport systems considers their pilot implementation as a milestone. The Electronic Route Guidance System (ERGS) launched in the US in 1969, the CACS (Comprehensive Automobile Traffic Control System) launched in Japan in 1973 and the ARI (Autofahrer-Rundfunk- Information system) are prominent systems of this period (T. C. Ministry of Transport, 2014).

In the 1980s, there were conditions for the development of smart transportation. It makes the operating system cheaper with the emergence of the memory unit in computers and new research and development efforts have begun with practical use. Work on the Road/Automobile Communication System (RACS) Project, which forms the basis of the current vehicle routing system in Japan, started in 1984. There are two projects, a more efficient and safer European Traffic System Program (PROMETHEUS) that initiated mainly by automobile manufacturers and a Road Infrastructure for Vehicle Safety (DRIVE) initiated by the European Union (Catapult, 2014).

By the end of the 1980s, concepts of automatic smart road and automatic smart vehicle in the transportation sector have been revived with developments of concepts like microprocessors, wireless communication devices and electronic sensors. After the 1990s, smart transportation systems, especially in the USA, Europe, and Japan, have begun to spread with constant development (Dia & Panwai, 2014).

The smart transportation standards period, which began in 1980 and lasted until the mid-1990s, is a time when intelligent transportation practices in developed countries were invented and used. It is accepted that since 1995, smart transportation applications period was entered. Thus, applications such as intelligent pedestrian navigation systems, mobile traffic information systems, lane violation warning systems, blind spot information systems, satellite technologies, mobile technologies including Bluetooth, Wi-Fi and e-call have been used.

Transportation is one of the most important factors affecting the economic development and welfare of a country. In today's world, transportation is changing rapidly with globalization and economic growth.

In the transportation sector, continuous economic growth, continuous population growth and increasing urbanization have become decisive for the industry's future. The increase in population leads to an increase in mobility requirements for both passenger transport and freight transport. However, safe, punctual, shorter time and more comfortable transport demands have accelerated the development of transport. Within this framework, concepts such as the operation of transportation types supported by logistics services, the establishment of an efficient transportation infrastructure and the creation of the concept of sustainability that emphasizes safety in transportation types have emerged.

3.2 Main Problems of Transportation and Smart Transportation Solutions

Transportation demands for freight transport are increasing as well as population growth in the world and our country, the complexity of supply chains and the development of the logistics industry. Some of these demands are increased safety in transport and delivery of needs in shorter time to the customer. The rapid increase in the number of roads and vehicles resulting from the developments in transportation industry, which is proportional to the increasing demand, leads to transportation delays, prolongation of load transportation, resource consumption, environmental problems and accidents. These adverse outcomes in the transport system require new, more efficient, effective, safe and economical design systems. For this reason, smart transportation approach has emerged that is supported by developing technologies to solve these problems and to bring cities to the future (Uckelmann, 2008). Some of the components of smart transportation are shown in Figure 3.1 (Dia & Panwai, 2014).

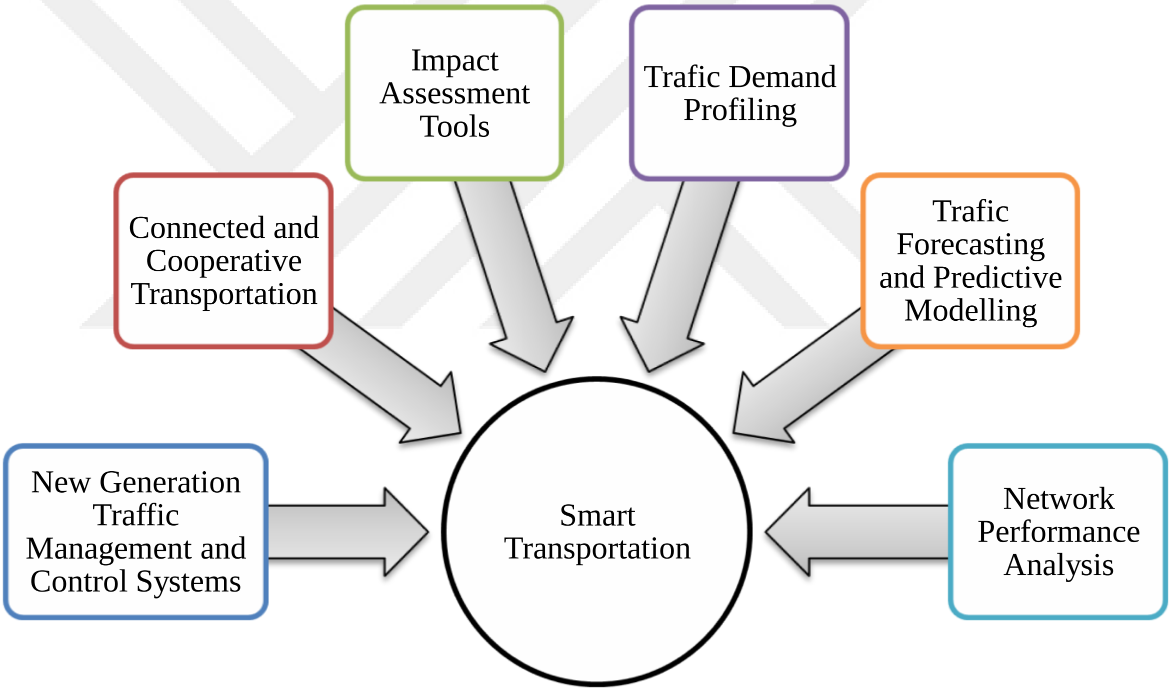

Figure 3.1: Smart Transportation Components

Smart Transportation Systems provide economic, environmental and socially sustainable solutions, in particular by ensuring that information is accessed quickly and efficiently. The objectives of the smart transport system are to provide multidimensional data exchange between human-vehicle-infrastructure-center, to use in accordance with the capacities of roads, to increase the safety and mobility of traffic, to reduce energy loss to the environment by providing energy efficiency (Tufan, 2014). Within the context of smart transportation, solutions to major transportation problems can be produced by using advanced information and communication technologies. With smart transportation applications, coordination between different types of transportation can be provided to create ideal traffic conditions, the efficiency and speed of services related to passenger, and freight movements can be increased (T. C. Ministry of Transport, 2014).

With smart transportation, timesavings and a more environment friendly transportation are provided and at the same time, the quality of the journeys is enhanced. It improves the performance of modern transport systems by optimizing travel times and reducing the risk of crashes and injuries. Smart transportation applications are used in areas of improving safety and security, helping to relieve congestion, environmental monitoring and protection, productivity and operational efficiency and comfort factors. Smart transportation applications increase the efficiency of road infrastructure by reducing the costs of infrastructure. It increases travel options and mobility by combining travel information and effective demand management (UNECE, 2012).

When considered as a general framework, the aims of ITS are as follows (UNECE, 2012; Zanelli, 2016; BVRLA, 2016):

- multidimensional data exchange between human-vehicle-infrastructure-center
- security of traffic
- the use of roads in accordance with their capacities
- increasing mobility
- reducing environmental damage by providing energy efficiency
- development of intelligent tools

3.3 Benefits of Smart Transportation

There are many benefits of smart transportation with systems such as traffic tracking systems, advanced passenger information systems, pricing systems, advanced transportation management systems and advanced public transportation systems (Viechnicki et al., 2015).

Road and public transport services, weather conditions, time and fare schedules and transfer information are provided to passengers with telephone, internet and other means of communication. Dynamic travel planning is provided to passengers by calculating the most appropriate travel plan and route selection for the user. At the pedestrian crossings, signal priorities and signal times are set depending on the pedestrian density and the duration of the wait (Tufan, 2014).

Smart transportation applications have been developed for monitoring and directing of vehicles carrying dangerous cargo. These applications that detect user violations of rules help to improve the driver's compliance behavior and help prevent potential accidents. At the same time, it informs meteorological events and roadside breakdowns or maintenance procedures.

Smart transportation applications enable, especially on commercial vehicles, to reduce travel time and to reduce operating costs by tracking vehicles routes. Thus, while increasing the profitability of individual operators with the economic savings to be achieved, it enables the sustainable growth of economies on a national scale in fair competition. These applications, which enable payroll systems to operate automatically and faster, shorten pay-to-pay queues and provide faster travel for users at affordable rates.

Another benefit provided by smart transportation applications is that it enables more efficient travel with less energy, particularly in road transport systems based on fossil fuel use. Thus, emissions of harmful gases can be reduced and environmental balance can be achieved by using the resources properly. Smart practices transportation will help city people to live in a healthier environment and help improve their quality of life (OTEP, 2014).

Some of benefits of smart transportation are as follows (T. C. Ministry of Transport, 2014; Catapult, 2014):

- Event management and driver information
- Motorway participation control
- Controlled lane application

- Smart road workshop
- Road weather information system
- Emergency vehicle priority system
- Signal control system
- Road user information system
- Passenger information systems
- Mobile and web traffic information applications
- Route planning
- Public transport priority
- Electronic fare collection systems

3.4 Literature Review

3.4.1 Literature Review of Smart Transportation

Today, smart transportation is a system based on advanced technologies in the regulation and management of transportation. These are systems that use real-time and up-to-date databases and serve to improve efficiency, safety and service quality in transportation. On the other hand, the integration of all transport systems on the technological and institutional basis, which enables people and goods to move from one place to another, is also considered within the concept of smart transportation (Yardım & Akyıldız, 2005).

The goal of smart transportation created by the use of information and communication technologies; to provide economic, environmental and social sustainable solutions such as traffic safety, appropriate use of roads, increase mobility, effective and instant access of information (Zanelli, 2016).

In the literature, Stefansson and Lumsden (2008) present the conceptual model of the smart transportation management system and analyze how the included factors change the performance of distribution activities and what management issues are at stake. Kim et al. (2010) proposes a reservation-based scheduling scheme for the charging station to decide the service order of multiple requests, aiming at improving the satisfiability of electric vehicles. Synergizing electrified vehicles and mobile information systems in smart transportation is presented by Schewel and Kammen (2010). Kumbhar (2012) developed Wireless sensor networks for smart transportation solution. Wang and Kexin (2013) discussed the benefits and problems of the three solutions of transportation, based on the Transit Priority Strategy in China, including the transportation policy research, smart transportation research, as well as planning and design research. Bacciu et al. (2017) analyzed the feasibility of these services in using machine learning for short-term predictions in smart transportation systems.

3.4.2 Literature Review of Smart Transportation with MCDM

There are many studies about smart transportation in the literature but its use with MCDM methods is very limited. Kolosz et al. (2013) modeled uncertainty in the sustainability of intelligent transport systems by using AHP. Moussa et al. (2013a) proposed MCDM approach with SMART, TOPSIS, AHP, PROMETHEE and ELECTRE for personalization of traveller’s information in public transportation. In addition, they presented MCDM approach with ELECTRE I for personalization in intelligent transport systems (Moussa et al., 2013b). In addition, De Krucker et al. (2015) developed two-stage multi criteria analysis for the future intelligent transport systems based safety innovation projects.

In this study, a different point of view will be presented using SWOT analysis, hesitant fuzzy linguistic MCDM methods for smart transportation strategy selection.

3.5 Smart Transportation Examples in Turkey

It is important that people travel safely and easily within cities, intercity or international. In developed countries, governments and local governments are working on ways to design safe, easy travel destinations, access to transportation with the integration of sustainable and innovative technologies (Public Technology Platform, 2016). In recent years, the number of smart transportation examples in Turkey has increased.

Firstly, with smart lighting systems, the location of defective lamps can be monitored from the center, the hours-based lamps can be switched on and off, and the remaining life of the lamps can be monitored. Smart irrigation systems can be used to create an irrigation timetable with weather forecasting and current soil moisture. In addition to these, there are also applications of Antalya Traffic Control Center and Traffic Electronic Control System (Karadağ, 2013).

Some examples of smart transport in Istanbul are (Yardım & Akyıldız, 2005; OTEP, 2014; T. C. Ministry of Transport, 2014; Deloitte Report, 2016):

Smart Parking Locations: Finding empty parking spaces is often difficult in big cities. Smart solutions can be used to optimize parking spaces. Each parking area can be equipped with a sensor that detects the occupancy or space condition.

Travel services: This solution utilizes the potential of unused vehicles and uses digital platforms and smart applications to sell travel services to people who need transportation.

Personalized transport information: Technology and data can be used for real-time and fully personalized transport directions. Smart solutions combine time schedules and data about public transport to find the most appropriate way of travel.

Intelligent traffic control: Real-time and detailed information on the traffic flow in the city is obtained via the sensors in the infrastructure and vehicles, enabling smart systems to optimize the traffic flow by arranging traffic lights and other signaling.

Harmonized, connected automobiles: Modern automobiles are equipped with numerous computer systems to enhance reliability and safety. Some of these systems have even automatized some manual functions such as parking the vehicle.

The other application in Istanbul is smart transportation applications such as Traffic Measurement Systems, Traffic Information Systems, Traffic Signaling Systems, Adaptive Traffic Management System, Traffic Control Systems, Public Transportation

Information Systems, and Public Transportation Camera Systems etc. With these systems, junctions are managed according to the instant traffic intensity. The traffic flow is monitored in real time and can be instantly interrupted in unusual situations. Traffic systems in the province center and districts are controlled and managed from a single point. Priority signaling is planned for public transport. Alternative solutions to traffic congestion caused by traffic accidents and road works are produced and implemented rapidly (Deloitte Report, 2015).

4. HESITANT FUZZY MCDM

4.1 Preliminaries of Hesitant Fuzzy Linguistic Term Sets

The complexity of the decision problems encountered in the real world is often due to the uncertainty of alternatives. The linguistic information is used to successfully manage this uncertainty. DMs are trying to make decisions by combining different information. However, it is difficult to decide when there are many criteria and not sufficient information. Therefore, MCDM approach based on HFLTS to reveal information in hesitate situations is proposed.

The hesitant fuzzy set (HFS) is first presented by Torra and Narukawa (2009) and the degree of membership of an element in these sets may have many possible values between zero and one. HFS is strongly useful in the expression of the existing hesitation when the DMs give the values of evaluation and they were a topic of big interest to the researchers (Torra, 2010).

Definition 1: X is defined as a universal set. HFS over X is defined as a function that will render a subset of [0, 1], which can be presented as (Torra, 2010):

$$E = \{< x, h_E(x) > | x \in X\} \tag{4.1}$$

Here, $h_E(x)$ is called a hesitant fuzzy element (HFE) and is defined as a set with values between [0, 1]. Possible degrees of adhesion of the element $x \in X$ to the set E are specified. H is the set of all HFE.

Definition 2: X is defined as a reference set. Let HFS over X is a function h which returns values between [0, 1]:

$$h: X \rightarrow \{[0, 1]\} \tag{4.2}$$

Hence, an HFS is described as the union of their membership functions.

Definition 3: $M = \{\mu_1, \mu_2, . . . , \mu_n\}$ is defined as a set of membership functions n. The HFS that is associated with M, h_M, is described as

$$h_M : M \rightarrow \{[0, 1]\} \tag{4.3}$$

$$h_M (x) = \bigcup_{\mu \in M} \{\mu(x)\} \tag{4.4}$$

Definition 4: The lower and upper boundaries of h, an HFS, are:

$$h^{-}(x) = min\ h(x) \tag{4.5}$$

$$h^{+}(x) = max\ h(x). \tag{4.6}$$

Definition 5: h is defined an HFS and the envelope of h, $A_{env(h)}$, is described as

$$A_{env(h)} = \{x, \mu_A(x), \nu_A(x)\} \tag{4.7}$$

with $A_{env(h)}$ being the intuitionistic fuzzy set (Atanassov, 1986) of h, and μ and v are, respectively, defined as

$$\mu_A(x) = h^{-}(x) \tag{4.8}$$

and

$$v_A(x) = 1 - h^{+}(x). \tag{4.9}$$

Liu and Rodriguez (2014) present an MCDM model where DMs express their evaluations with linguistic expressions. This model presents these expressions by representing a set of HFLTS.

Definition 6: S is defined as a set of linguistic terms, $S = \{s_0, . . . , s_g\}$. An HFLTS, H_s, is an ordered finite subset of the sequential linguistic terms of S.

Definition 7: The upper bound H_{s+} and lower bound H_{s-} of the HFLTS are described as

$$H_{s+} = max(s_i) = s_j\ , s_i \in H_S\ et\ s_i \le s_j\ \forall i; \tag{4.10}$$

$$H_{s-} = min(s_i) = s_j\ , s_i \in H_S\ et\ s_i \le s_j\ \forall i; \tag{4.11}$$

*Definition 8***:** Suppose that E_{GH} is a function that transforms expressions in words into HFLTS, H_S. Let G_H be an out-of-context grammar that utilizes the linguistic term set in S. Let S_{ll} be the expression domain generated by G_H. This relationship can be represented as:

$$E_{GH} : S_{ll} \rightarrow H_s \tag{4.12}$$

Using the following approach, comparative linguistic expressions can be transformed into HFLTS:

$$E_{GH}\ (s_i) = \{s_i | s_i \in S\} \tag{4.13}$$

$$E_{GH}\ (at\ most\ s_i) = \{s_j | s_j \in S\ and\ s_j \le s_i\} \tag{4.14}$$

$$E_{GH}\ (less\ than\ s_i) = \{s_j | s_j \in S\ and\ s_j < s_i\} \tag{4.15}$$

$$E_{GH}\ (at\ least\ s_i) = \{s_j | s_j \in S\ and\ s_j \ge s_i\} \tag{4.16}$$

$$E_{GH}\ (greater\ than\ s_i) = \{s_j | s_j \in S\ and\ s_j > s_i\} \tag{4.17}$$

$$E_{GH}\ (between\ s_i\ and\ s_j) = \{s_k | s_k \in S\ and\ s_i \le s_k \le s_j\} \tag{4.18}$$

Definition 9: The envelope of the HFLTS, *env*(H_S), is a linguistic interval with the upper bound (max) and the lower bound (min) as shown below:

$$env(H_S) = [H_{s-}\ , H_{s+}]\ , H_{s-} \le H_{s+} \tag{4.19}$$

4.2 Literature Review

4.2.1 Literature Review of Hesitant Fuzzy MCDM

Realistic decision-making problems are usually too complex and poorly structured to lead the optimal decision. In fact, a one-dimensional approach is an over-simplification of the real nature of the problem and it can lead to unrealistic decisions. MCDM is an advanced area of operations research that focuses on the development and implementation of decision-making tools and methodologies to confront complex decision issues. MCDM allows you to make decisions when you have multiple and usually contradictory criteria. The MCDM is one of the most popular methods by the research workers in the literature.

There are two branches in MCDM. These are multi-attribute decision-making (MADM) and multi-objective decision-making (MODM). MADM generally includes the discrete decision variables and a limited number of alternatives for evaluation (Jato-Espino et al., 2014). MODM is concerned with determining the best choice from an infinite set of alternatives under a set of constraints. Each criterion in MODM is associated with an objective, whereas in MADM each criterion is associated with a discrete attribute (Kabir et al., 2014). However, MADM and MCDM have been used to refer the same class of problems in the recent years.

MCDM gives the best of all alternatives in the environment of multiple, usually conflicting, decision criteria. Priority based, outranking, distance-based and mixed methods can be considered as the main classes of the current methods (Pomerol & Romero, 2000). Experts are trying to make decisions by combining different information. However, it is difficult to decide when there are not many criteria and sufficient information. Therefore, a hesitant fuzzy MCDM approach that deals with comparative hesitant fuzzy linguistic term sets (HFLTS) to reveal information in hesitate situations.

In particular, the hesitant fuzzy sets (HFS) have been progressively used for decision-making problems that are multi criteria in recent years. A new representation of the

HFLTS by means of a fuzzy envelope was made to carry out the computing with words processes by Liu and Rodriguez (2013). Xu (2014) provides with a thorough and systematic introduction to hesitant fuzzy theory. He presents advanced methods about hesitant fuzzy aggregation techniques, hesitant fuzzy preference relations, hesitant fuzzy measures, hesitant fuzzy clustering algorithms and hesitant fuzzy multi-attribute decision-making methods.

There are several hesitant fuzzy MCDM studies. Table 4.1 lists some of these studies.

Table 4.1a: Literature Review of Hesitant Fuzzy MCDM

Author (Year)	Objective of the Study	Method	Type
Zeng et al. (2013)	to present a MCDM to tackle hesitant fuzzy information	hesitant fuzzy MULTIMOORA	Illustrative Example
Zhang & Wei (2013)	to develop the E-VIKOR and TOPSIS method to solve the MCDM problems	E-VIKOR and TOPSIS	Illustrative Example
Yu et al. (2013)	to explore aggregation methods for prioritized hesitant fuzzy elements	generalized hesitant fuzzy prioritized weighted average (GHFPWA) and generalized hesitant fuzzy prioritized weighted geometric (GHFPWG)	Illustrative Example
Zhu & Xu (2013)	to define a concept of hesitant Bonferroni element	Bonferroni Means	Illustrative Example
Liao & Xu (2013)	to develop the classical VIKOR method to accommodate hesitant fuzzy circumstances	VIKOR	Illustrative Example
Beg & Rashid (2013)	aggregating the opinions of decision makers on various criteria	hesitant fuzzy TOPSIS	Illustrative Example
Wei & Zhang (2014)	to present concepts of hesitant fuzzy set and define the Shapley value-based LP metric	VIKOR	Illustrative Example
Liao et al. (2014)	to present the concepts of multiplicative consistency, perfect multiplicative consistency and acceptable multiplicative consistency for a hesitant fuzzy preference relation	hesitant fuzzy preference relation	Illustrative Example

Table 4.1b: Literature Review of Hesitant Fuzzy MCDM

Author (Year)	Objective of the Study	Method	Type
Peng et al. (2014)	to explain the applicability and effectiveness of the developed approach	hesitant interval valued fuzzy sets	Illustrative Example
Li & Peng (2014)	to propose a new operator for gas areas selection with interval-valued hesitant fuzzy information	the interval-valued hesitant fuzzy Hamacher synergetic weighted averaging (IVHFHSWA) operators and their geometric version (IVHFHSWG) operators	Illustrative Example
Wu et al. (2014)	to present the MCDM problems in which the criteria are in different priority levels and the criteria values take the form of hesitant fuzzy linguistic numbers	hesitant fuzzy linguistic numbers	Illustrative Example
Liao et al. (2014)	to develop weight determining methods for hesitant fuzzy MCDM	hesitant fuzzy OWA operator	Illustrative Example
Zhang & Xu (2014)	to extend the TODIM method to solve problems under hesitant fuzzy environment	TODIM	Illustrative Example
Wei et al. (2014)	to propose comparison methods and the aggregation theory for HFLTS	linguistic OWA operator	Case study
Bin & Zeshui (2014)	to develop hesitant multiplicative method of programming	hesitant AHP	Illustrative Example
Dağ & Önder (2014)	to determine the appropriate service location providing the most satisfaction of company	VIKOR	Case study
Kahraman et al. (2014)	to develop a MCDM model that considers the complexity and imprecision strategic decisions	hesitant fuzzy TOPSIS	Case study
Wang et al. (2014)	to explain the accuracy and applicability of the method HFS	HFS	Illustrative Example
Mousavi et al. (2014)	Selecting the best alternative	hesitant AHP	Illustrative Example
Huchang et al. (2014)	to develop a method to solve the problem of MCDM in the context of HFLTS	HFL VIKOR	Illustrative Example

Table 4.1c: Literature Review of Hesitant Fuzzy MCDM

Author (Year)	Objective of the Study	Method	Type
Wang et al. (2014)	to propose MCDM problems in different priority levels and the criteria values take the form of interval-valued hesitant fuzzy linguistic numbers (IVHFLNs)	IVHFLNs	Illustrative Example
Tan et al. (2015)	to extend Choquet-based TODIM method to solve the hesitant fuzzy MCDM problems	TODIM	Illustrative Example
Ahmad et al. (2015)	to develop the traditional VIKOR method to solve GDM problem under hesitant fuzzy environment	VIKOR	Illustrative Example
Chen & Xu (2015)	to develop HF-ELECTRE II approach that combines of HFS	HF-ELECTRE II	Illustrative Example
Chen et al. (2015)	to develop hesitant fuzzy ELECTRE I method	HF-ELECTRE I	Illustrative Example
Peng et al. (2015)	to present a hesitant fuzzy ELECTRE method	hesitant fuzzy ELECTRE	Illustrative Example
Wei et al. (2015)	to extend the classical TODIM method with HFLTS and considering the decision maker's psychological behavior	TODIM	Illustrative Example
Liao et al. (2015)	to develop HFL cosine distance measure	VIKOR	Case study
Yu et al. (2015)	to propose the linguistic hesitant fuzzy methods	linguistic hesitant fuzzy arithmetic Heronian mean (LHFAHM) operator, LHFWAHM operator, LHFGHM operator, LHFWGHM operator	Illustrative Example
Yavuz et al. (2015)	to propose a hierarchical hesitant fuzzy linguistic for alternative-fuel vehicles	hierarchical HFL model	Case study
Mousavi & Tavakkoli Moghaddam (2015)	to propose a hierarchical COPRAS method to consider subjective judgments and objective opinions based on the HFS theory	COPRAS	Case study
Gitinavard (2015)	to propose a novel soft computing approach based on new interval-valued hesitant fuzzy IVHF-COPRAS	IVHF-COPRAS	Illustrative Example

Table 4.1d: Literature Review of Hesitant Fuzzy MCDM

Author (Year)	Objective of the Study	Method	Type
Xue et al. (2016)	to present an integrated approach for handling robot selection problems	hesitant 2-tuple linguistic QUALIFLEX algorithm	Case study
Senvar et al. (2016)	to propose MCDM process with hesitant fuzzy sets	TOPSIS	Case study
Huan (2016)	to focus on a MCDM approach with linguistic hesitant fuzzy sets	Hesitant TOPSIS - TODIM	Case study
Yu et al. (2016)	to propose new methods	quasi-hesitant fuzzy linguistic harmonic averaging (Quasi-HFLHA) and Quasi-HFLWHA operator	Illustrative Example
Lourenzutti & Krohling (2016)	to develop generalization of the TOPSIS method	GMo-RTOPSIS (Group Modular Random TOPSIS)	Case study
Wang & Xu (2016)	to develop the total orders of HFEs for MCDM	OWA Operator	Illustrative Example
Peng et al. (2016)	to develop hesitant fuzzy MCDM methods based on prospect theory	TODIM, PROMETHEE	Illustrative Example
Tan (2016)	to present a comparison formula of HFLTS based on probability criterion of uniform distribution	TOPSIS	Illustrative Example
Gou et al. (2017)	propose hesitant fuzzy linguistic entropy and cross-entropy measures	hesitant fuzzy linguistic alternative queuing method (HFL-AQM)	Case study
Ren et al. (2017)	to propose an approach for GDM with dual hesitant fuzzy information	VIKOR	Illustrative Example
Mousavi et al. (2017)	to present decision model under a hesitant fuzzy environment for solving the GDM problems in energy sector	ELECTRE	Case study
Yu (2017)	to propose new methods under the hesitant fuzzy environment	Heronian Operator	Illustrative Example
Li et al. (2018)	to propose a new hesitant consistency measure, called interval consistency index	hesitant fuzzy linguistic preference relations	Illustrative Example
Liao et al. (2018)	to propose two new approaches named the score-deviation-based ELECTRE II method and the positive and negative ideal hesitant fuzzy linguistic elements based ELECTREII method	ELECTRE II	Illustrative Example

Table 4.1e: Literature Review of Hesitant Fuzzy MCDM

Author (Year)	Objective of the Study	Method	Type
Li et al. (2018)	to modified TODIM with HFLTS	TODIM	Case study
Liao et al. (2018)	to propose a linguistic scale function to transform the semantics corresponding to linguistic terms	hesitant fuzzy linguistic preference utility (HFLPU) TOPSIS – HFLPU VIKOR	Case study
Huang et al. (2018)	to develop new method to overcome the insufficiencies of the traditional QFD	QFD based on proportional hesitant fuzzy linguistic term set (PHFLTS)	Illustrative Example
Zhou et al. (2018)	to propose MCDM approaches based on distance measures for HFLTS	TOPSIS – VIKOR - TODIM	Illustrative Example

4.2.2 Literature Review of Hesitant HFL SAW

The SAW method, also known as the weighted sum method, is the most widely used MCDM method (Hwang & Yoon, 1981). The basic principle of SAW is to obtain a weighted sum of the performance ratings of each alternative. The method is based on a weighted average. An evaluation score is calculated for each alternative. The advantage of this method is that there is a proportional linear transformation of raw data; this means that the relative order of the sizes in the standardized points remains the same. The advantage of this method is that there is a proportional linear transformation of raw data (Chang & Yeh, 2001).

Chou et al. (2008) proposed the Fuzzy Simple Additive Weighting (FSAW) method to solve problems under fuzzy environment. Thus, it is possible to extend this method under hesitant fuzzy linguistic environment. In this study, the SAW method integrated with HFLTS will be studied.

4.2.3 Literature Review of SWOT Analysis with MCDM

SWOT analysis is a strategic approach, which is used to determine the strengths and weaknesses of a situation to be assessed, and to identify opportunities and threats taking into account both the internal and external environments. This approach should describe both positive and negative internal and external factors in a comprehensive way to assess the situation and achieve success (Dincer et al., 2015).

SWOT analysis has two main benefits: First, SWOT analysis is performed to identify the status of the situation. In this framework, the strengths and weaknesses of the situation and the opportunities and threats faced by the situation are tried to be revealed. In this sense, SWOT is a "current situation" analysis. In addition, an analytical technique helps to identify and predict what the future state of the situation will be. In this second sense, SWOT is a "future situation" analysis.

One of the limitations of the SWOT analysis is that in the decision making process, the importance of each factor is not quantified. For this reason, it is hard to determine which SWOT factor has the greatest effect on strategic decisions. However, when the SWOT approach is used in conjunction with the AHP technique, it can provide a quantitative measure of importance for each factor (Kurttila et al., 2000).

In the proposed integrated model, SWOT analysis is implemented as a state-configuration approach to support the HFL AHP, HFL CODAS and HFL COPRAS methods in decision-making.

The SWOT approach examines a situation in all its aspects. In particular, it allows to classify factors as internal (strengths, weaknesses) and external (opportunities, threats) and thus to contrast strengths and opportunities with weaknesses and threats.

In particular, SWOT analysis, which is used to identify the criteria and alternatives required for an MCDM problem in a very detailed way, is also used with fuzzy MCDM methods. Some of the studies on SWOT with the fuzzy MCDM method are shown in Table 4.2.

As shown in Table 4.2, SWOT analysis in the literature is supported generally by methods based on the fuzzy approach. Its use with advanced fuzzy MCDM methods such as intuitionistic, interval type-2 fuzzy, hesitant fuzzy linguistic etc. is limited.

There is only one study about SWOT analysis with HFL method and in his study; any MCDM method was not used.

In this study, a more advanced technique, the HFL approach with MCDM methods, is presented. The factors determined by SWOT are weighted by HFL AHP and the selection of the most appropriate strategy is done by HFL CODAS and HFL COPRAS.

Table 4.2a: Studies of SWOT with Fuzzy MCDM methods

Authors (Year)	Application Area	Uncertainty Level	Techniques
Kahraman et al. (2008)	strategies for e-government applications in Turkey	Fuzzy-Type I	FAHP
Zaerpour et al. (2008)	make-to-order (MTO) or make-to-stock (MTS) strategy for product	Fuzzy-Type I	FAHP
Lee & Lin (2008)	environmental evaluation of an international distribution center	Fuzzy-Type I	FAHP
Çelik et al. (2009)	evaluation model on academic personnel recruitment in MET institutions	Fuzzy-Type I	FAHP-FTOPSIS
Çelik et al. (2009)	competitive strategies on Turkish container ports in maritime transportation network	Fuzzy-Type I	Fuzzy axiomatic design (FAD)-FTOPSIS
Hatami-Marbini & Saati (2009)	strategy selection	Fuzzy-Type I	FTOPSIS
Khorshid & Ranjbar (2010)	strategy selection	Fuzzy-Type I	FAHP-FANP-FTOPSIS
Rezaie et al. (2010)	organizational safety strategies in a textile company in Iran	Fuzzy-Type I	FAHP-FDEMATEL-ELECTRE
Manteghi & Zohrabi (2011)	comprehensive framework in order to formulate strategy in organizations	Fuzzy-Type I	FQFD
Ghorbani et al. (2011)	strategy priorities	Fuzzy-Type I	FTOPSIS

Table 4.2b: Studies of SWOT with Fuzzy MCDM methods

Authors (Year)	Application Area	Uncertainty Level	Techniques
Ekmekçioğlu et al. (2011)	nuclear power plant site selection	Fuzzy-Type I	FAHP-FTOPSIS
Babaesmailli et al. (2012)	prioritization the strategies for tile manufacturing firm	Fuzzy-Type I	FANP
Pur & Tabriz (2012)	strategy formulation in Petrokaran Film Factory	Fuzzy-Type I	FQFD
Sevkli et al. (2012)	airline industry in Turkey	Fuzzy-Type I	FAHP-FANP
Çelik & Kandakoğlu (2012)	maritime policy development against ship flagging out dilemma	Fuzzy-Type I	FAHP
Bas (2013)	analysis of electricity supply chain	Fuzzy-Type I	AHP-FTOPSIS
Hatami-Marbini et al. (2013)	solar panel manufacturing firm in Canada	Fuzzy-Type I	Fuzzy Compromise Ratio Method (FCRM)
Forghani & Izadi (2013)	contractor selection	Fuzzy-Type I	FTOPSIS-FVIKOR
Ebonzo et al. (2013)	strategy priorities	Axiomatic Fuzzy	AHP-TOPSIS
ArshadiKhamseh & Fazayeli (2013)	factors priorities in Drug Distribution Company	Fuzzy-Type I	FANP
Lee (2013)	development of strategy formulation	Fuzzy-Type I	FANP
Izadi & Mohammadi (2013)	process for contractor selection	Fuzzy-Type I	FAHP
Esmaeili et al. (2014)	best strategies for the oil industry	Fuzzy-Type I	AHP-FTOPSIS
Sheykhan et al. (2014)	strategy priorities	Fuzzy-Type I	PROMETHEE II
Nikjoo & Saeedpoor (2014)	components in Iranian insurance industry	Intuitionistic Fuzzy	Fuzzy DEMATEL
Azarnivand et al. (2015)	water and environmental management	Fuzzy-Type I	FAHP
Ren et al. (2015)	strategic recommendations for the responsible development of biofuel in China	Fuzzy-Type I	FAHP

Table 4.2c: Studies of SWOT with Fuzzy MCDM methods

Authors (Year)	Application Area	Uncertainty Level	Techniques
Zare et al. (2015)	analysis the electricity supply chain in north-west Iran	Fuzzy-Type I	AHP-FTOPSIS
Arabzad et al. (2015)	supplier selection and order allocation	Fuzzy-Type I	FTOPSIS
Nejjad (2015)	prioritization of human resources strategies	Fuzzy-Type I	FANP
Singh et al. (2015)	strategy priorities in tourism industry	Fuzzy-Type I	FAHP
Adar et al. (2016)	sustainable energy management with sewage sludge in Turkey	Fuzzy-Type I	FAHP
Groselj et al. (2016)	forest (ecosystem) management	Fuzzy-Type I	FANP
Shakerian et al. (2016)	human resources and business strategies in organizations	Fuzzy-Type I	FTOPSIS
Tavana et al. (2016)	outsourcing reverse logistics	Intuitionistic Fuzzy	FAHP
Toklu et al. (2016)	realization of strategic planning in manufacturing firms	Fuzzy-Type I	FANP
Arsic et al. (2017)	prioritization strategies of sustainable development of ecotourism in National Park Djerdap, Serbia	Fuzzy-Type I	ANP-FANP
Kececi & Arslan (2017)	root cause analysis of ship accidents	Fuzzy-Type I	FAHP-SHARE technique
Shahba et al. (2017)	mine waste management	Fuzzy-Type I	FAHP-FTOPSIS
Ervural et al. (2017)	Turkey’s energy planning	Fuzzy-Type I	ANP-FTOPSIS
Baykasoğlu & Gölcük (2017)	strategy selection	Interval type-2 fuzzy	IT2F-DEMATEL - IT2F TOPSIS
Friedrichsen et al. (2017)	categorization of these university strategies	Fuzzy-Type I	FAHP
Adem et al. (2018)	evaluation occupational safety risks in life cycle of wind turbine	Hesitant fuzzy linguistic	-

4.2.4 Literature Review of Hesitant HFL AHP

The AHP method, developed by Saaty (1980), is the most widely applied model of MCDM. AHP is a strong and simple decision-making tool to prioritize different factors. Hesitancy is a common phenomenon in the decision making process. The AHP is used in conjunction with hesitancy if the decision-making process is in an uncertain environment. Many possible values are used in HFL AHP to describe the hesitancy of the assessment of the DMs. The judgment represented by several possible values is called as a hesitant judgment (Zhu et al., 2016).

In literature, there are many studies about AHP, fuzzy AHP or advanced fuzzy AHP but the use of the AHP method based on HFLTS with hesitant fuzzy environment is not very common. Zhu and Xu (2014) developed AHP method with group decision-making. Mousavi et al. (2014) presented the hesitant fuzzy sets for the AHP method. Hesitant fuzzy AHP method involving multi-experts' linguistic evaluations aggregated by ordered weighted averaging (OWA) operator was developed by Oztaysi et al. (2015). Yavuz et al. (2015) is suggested multi-criteria evaluation of alternative-fuel vehicles with a hierarchical hesitant fuzzy linguistic model. Onar et al. (2016) presented computer workstation selection by using hesitant fuzzy QFD with HFLTS based AHP and TOPSIS. Kahraman et al. (2016) proposed humanitarian logistics location selection using hesitant fuzzy AHP. Huang and Yang (2016) represented pairwise comparisons in AHP using hesitant cloud linguistic term sets. Çolak and Kaya (2017) is prioritized renewable energy alternatives by using integrated AHP based on interval type-2 fuzzy sets and hesitant fuzzy TOPSIS methods. Tüysüz and Şimşek (2017) presented HFLTS based AHP for analyzing the performance evaluation factors in cargo sector. Fuzzy AHP with group decision-making under uncertainty using intuitionistic and hesitant fuzzy sets was presented by Kahraman and Tüysüz (2017). Kahraman et al. (2017) proposed a hesitant fuzzy linguistic AHP method for the selection marketplace among B2C firms.

4.2.5 Literature Review of Hesitant HFL CODAS

COmbinative Distance-based ASsessment (CODAS) is an MCDM method and this method was first introduced by Keshavarz Ghorabaee et al. (2016). In addition, comparison of new MCDM methods including CODAS for material handling equipment selection is presented by Mathew and Sahu (2018). Badi et al. (2018) present a study about supplier selection for a steelmaking company in Libya by using CODAS.

It has some features that have not been considered in the other MCDM methods. In this method, the Euclidean and Taxicab distances from the negative-ideal point measure the overall performance of an alternative. If the Euclidean distances of two alternatives have the same value, then Taxicab distance is used to find out the best alternative.

In this method, under fuzzy environment Euclidean and Taxicab distances values cannot be used because these distances define only for crisp environment. Therefore fuzzy weighted Euclidean distance and fuzzy weighted Hamming distance (Li, 2007) are used for selection. In literature, Ghorabaee et al. (2017) presented fuzzy extension of the CODAS method for multi-criteria market segment evaluation and Panchal et al. (2017) proposed an integrated fuzzy AHP-CODAS framework in urea fertilizer industry.

The use of the CODAS method with advanced fuzzy techniques is not common. Peng and Garg (2018) present interval-valued fuzzy soft set (IVFSS) based CODAS and WDBA. There is only one study on intuitionistic fuzzy CODAS approach (Ren, 2018) and there is not any study about hesitancy. Therefore, this is the first study, which integrates HFL approach and CODAS method.

4.2.6 Literature Review of Hesitant HFL COPRAS

Recently, hesitant fuzzy MCDM has been used by various authors in various fields. This work will also lead to the HFL COPRAS method for selection. The COPRAS approach was first introduced by Zavadskas, Kaklauskas and Sarka (1994). This method expects direct and proportional reliance of importance and utility level of examined choices on a system of criteria satisfactorily describing the options, and on qualities and weights of the criteria. It was utilized to take care of different issues in development.

COPRAS can be used for both of the maximum and minimum criterion values in a multi-criteria evaluation. It can be easily applied to complex criteria and problems involving multiple alternatives. Because of these components, applications have been made in many different areas in the literature.

Zadeh (1965) presented fuzzy logic that could consider the vulnerability and solve the problems without sharp limits and exact qualities. There are also authors who apply the COPRAS method together with fuzzy logic such that fuzzy COPRAS method to investigate the regeneration options of derelict buildings in rural areas at Lithuania (Zavadskas & Antucheviciene, 2007), fuzzy COPRAS, TOPSIS and VIKOR techniques with respect to ranking of redevelopment of derelict buildings (Antucheviciene et al., 2011), the fuzzy COPRAS to provide a risk analysis framework (Yazdani, Alidoosti & Zavadskas, 2011). Turanoglu Bekar et al. (2016) developed new performance measurement in productive maintenance with fuzzy COPRAS.

The use of the COPRAS method with hesitant fuzzy environment is not very common. Firstly, Mousavi and Tavakkoli-Moghaddam (2015) presented a hierarchical COPRAS method to consider subjective judgments and objective opinions based on the HFS theory for multi-criteria group decision-making (MCGDM) problems. Büyüközkan et al. (2017) presented cloud computing technology selection methodology with interval valued intuitionistic fuzzy COPRAS. A soft computing based new interval-valued hesitant fuzzy multi-criteria group assessment method with interval-valued hesitant fuzzy complex proportional assessment (IVHF-COPRAS) method that can be applied in solving the MCGDM problems under uncertainty is proposed by Gitinavard et al. (2017). Peng and Dai (2017) presented three hesitant fuzzy soft decision making methods based on WASPAS, MABAC and COPRAS with combined weights.

In the literature, the COPRAS method is used together with advanced fuzzy techniques such as hesitant fuzy, interval-valued hesitant fuzzy. However, the use of COPRAS method based on HFLTS with envelope will be applied for the first time in this study.

The HFL COPRAS method helps the experts to decrease the errors by assigning membership degrees under a set. This method evaluates alternatives by using HFLTS and determines the rating of alternatives.

5. PROPOSED EVALUATION FRAMEWORK

5.1 Description of Evaluation Framework

Smart city approach that improves problems of the growing population has many components. Work has been recently accelerated for smart city models that help to raise the level of social prosperity in living spaces that have become a complex network, and allow them to grow and manage development with a sustainable method. It is possible to see many different smart city models in these different studies. It is very important to analyze the existing situation and determine the appropriate strategy when transitioning to a new formation.

In this study, a comprehensive smart city model with all kinds of components is created with the help of literature studies and expert opinions. Analytical methods are used to determine the focal point in the proposed smart city model. The proposed smart city model in the first phase of the study is considered as an MCDM problem.

The mixed structure of the smart cities evaluation involves many various and contradictory criteria. However, it is difficult to decide on, and rank smart cities when information is of uncertain nature. Sometimes DMs have difficulties to express their thoughts by numbers because these quantitative values are far from their own way of thinking in daily life. Furthermore, DMs can express their opinions more comfortably with words, instead of crisp numbers. The HFLTS (Torra & Narukawa, 2009) overcomes the uncertainty of this MCDM problem.

In the first phase, weights of smart city components are determined with HFL SAW method by collecting linguistic data from three DMs. Relationship matrix between main dimensions and components is constructed by collecting linguistic data from three DMs and most appropriate main dimension in proposed smart city model is obtained.

In order to make a decision, it is necessary to examine all the main factors in the interior and the exterior. SWOT analysis is a systematic approach that supports decision-making and determines the most important internal and external factors (Kandakoglu et al., 2009). According to the most appropriate main dimension, SWOT factors are determined with literature review and expert opinions in second phase.

HFL AHP method is used to define the final relative weights and priority factors. It is one of the significant methods for MCDM problems. This method is based on pairwise comparisons with hesitant judgments and gives the managers state control capability. It is a method that helps managers to classify targets and paths in a complex environment.

HFL CODAS and HFL COPRAS are MCDM method that evaluates the alternatives in linguistic expressions in hesitate situation, determines their distances to the optimal solution, and selects the most appropriate strategy. The flow chart of this methodology is given in Figure 5.1.

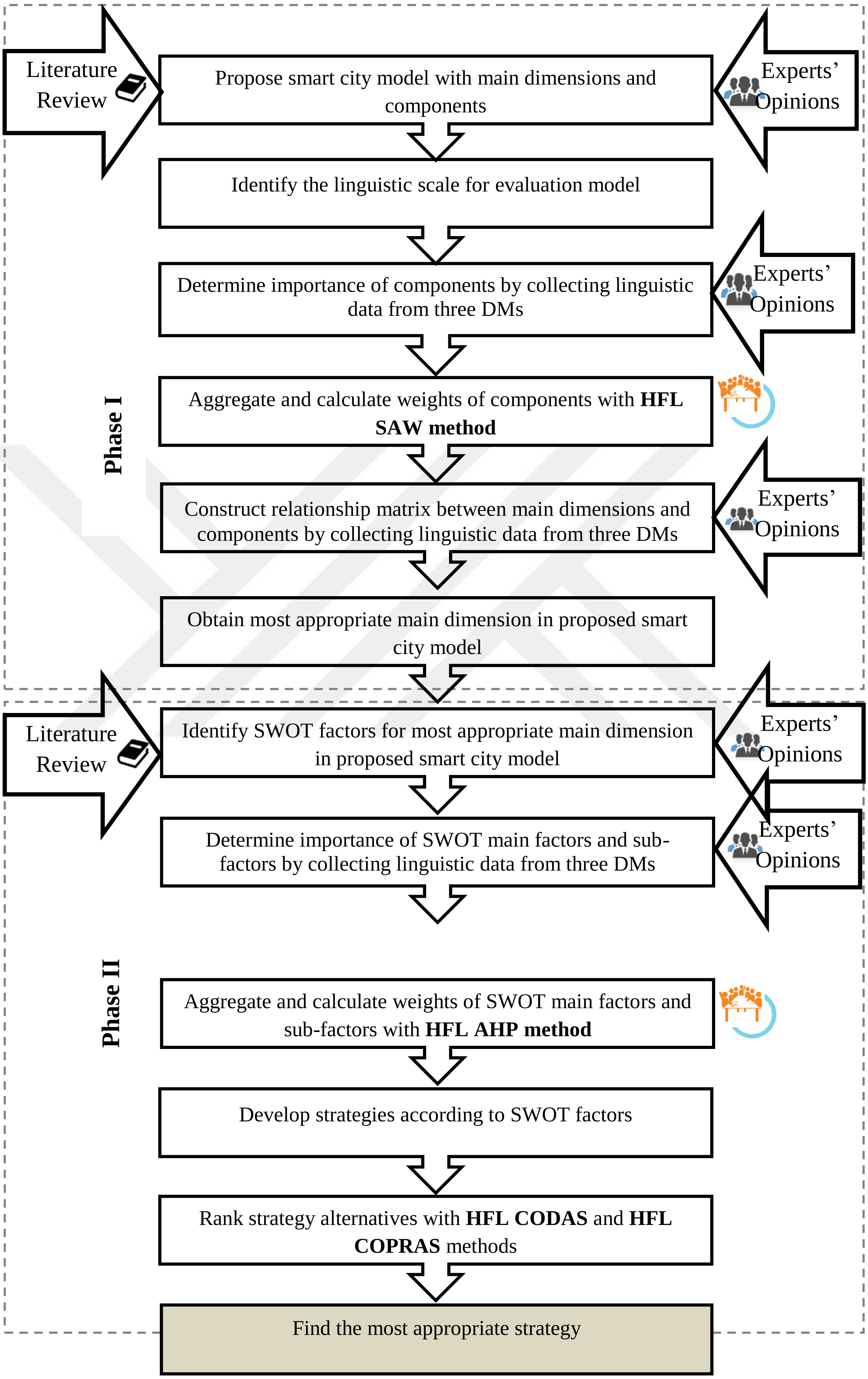

Figure 5.1: Flowchart of the Proposed Evaluation Approach

5.2 Phase I: Evaluation of Proposed Smart City Model based on HFL MCDM

5.2.1 HFL SAW Method for Weighting of Smart City Model based on HFL MCDM

The steps of the HFL SAW method are as follows:

Step 1. DMs evaluate criteria using linguistic terms in Table 5.1. The linguistic expression is voiced by the DM based on a context-free grammar, as shown in Definition 8.

Table 5.1: Linguistic Scale for HFL SAW (Beg & Rashid, 2013)

Linguistic term	S_i	Abb.	Fuzzy Numbers
None	s_{-3}	N	(0,0,0.17)
Very Low	s_{-2}	VL	(0,0.17,0.33)
Low	s_{-1}	L	(0.17,0.33,0.5)
Medium	s_0	M	(0.33,0.5,0.67)
High	s_1	H	(0.5,0.67,0.83)
Very High	s_2	VH	(0.67,0.83,1)
Perfect	s_3	P	(0.83,1,1)

Step 2. These linguistic expressions are converted to the HFLTS judgment matrix with the help of the transformation function E_{GH} as given in Definition 8.

Step 3. Let $Dt = \{d_1,d_2,...,d_k\}$ be a committee of k DMs, $Ai = \{a_1,a_2,...,a_I\}$ be a discrete set with I member alternatives, $Cj = \{c_1,c_2,...,c_J\}$ be a set consisting of the decision criteria, be the degree of importance of each DM, where $0 \leq I_t \leq 1,\ t = 1,2,...,k$, and $\sum_{t=1}^{k} I_t = 1$, $\widetilde{\omega t}$ be the fuzzy weight of the DMs. The degree of importance I_t is computed as:

$$I_t = \frac{d(\widetilde{w_t})}{\sum_{t=1}^{k} d(\widetilde{w_t})}, t = 1,2,\ldots,k \tag{4.20}$$

where $d(\widetilde{w_t})$ gives the defuzzified value of the fuzzy weight by using the signed distance.

Step 4. Aggregated fuzzy weights of individual attributes ($\widetilde{W_j}$) are computed. The aggregated fuzzy attribute weight, $\widetilde{W_j} = (a_j, b_j, c_j, d_j)$ of criterion *Cj* assessed by the committee of *k* DMs is computed as:

$$\widetilde{W_j} = (I_1 \otimes \widetilde{W_{j1}}) \oplus (I_2 \otimes \widetilde{W_{j2}}) \oplus \ldots \oplus (I_k \otimes \widetilde{W_{k1}}) \quad (4.21)$$

where $a_j = \sum_{t=1}^{k} I_t a_{jt}$, $b_j = \sum_{t=1}^{k} I_t b_{jt}$, $c_j = \sum_{t=1}^{k} I_t c_{jt}$, $d_j = \sum_{t=1}^{k} I_t d_{jt}$.

Step 5. The fuzzy weights of criteria are defuzified. The defuzzification of $\widetilde{W_j}$ is denoted as $d(\widetilde{W_j})$ and computed as:

$$d(\widetilde{W_j}) = \frac{1}{4}\left(a_j + b_j + c_j + d_j\right), j = 1,2,\ldots,n \quad (4.22)$$

Step 6. Normalized weight of criterion *Cj* is denoted as W_j and computed as:

$$W_j = \frac{d(\widetilde{W_j})}{\sum_{j=1}^{n} d(\widetilde{W_j})}, j = 1,2,\ldots,n \quad (4.23)$$

where $\sum_{j=1}^{n} W_j = 1$ and the weight vector $W=(W_1, W_2, \ldots, W_n)$ is constructed.

5.3 Phase II: SWOT Analysis of Smart Transportation based on HFL MCDM

5.3.1 HFL AHP Method for Weighting of SWOT Factors

*Definition 9***:** Let $A = \{a_1, a_2, \ldots, a_n\}$ be a set of values to be aggregated, OWA (ordered weighted average) operator *F* is defined as

$$F(a_1, a_2, \ldots, a_n) = wb^T = \sum_{i=1}^{n} w_i b_i, \quad (4.24)$$

where $w = (w_1, w_2, \ldots, w_n)^T$ is a weighting vector, such that $w_i \in [0, 1]$ *et* $\sum_{i=1}^{n} w_i = 1$ and *b* is the associated ordered value vector, where $b_i \in$ b is the i^{th} largest value in *A*.

The following steps of HFL AHP (Onar et al., 2016) are taken to make an organizational decision to generate priority:

Step 1. First, pairwise comparison matrices are created and the compromise evaluations from the DMs are obtained with HFLTS, which are found with the help of linguistic terms in Table 5.2.

Table 5.2: Linguistic scale for HFL AHP (Onar et al., 2016)

Linguistic terms	si	Abb.	Triangular fuzzy number
Absolutely high importance	s10	(AHI)	(7,9,9)
Very high importance	s9	(VHI)	(5,7,9)
Essentially high importance	s8	(ESHI)	(3,5,7)
Weakly high importance	s7	(WHI)	(1,3,5)
Equally high importance	s6	(EHI)	(1,1,3)
Exactly low importance	s5	(EE)	(1,1,1)
Equally low importance	s4	(ELI)	(0.33,1,1)
Weakly low importance	s3	(WLI)	(0.2,0.33,1)
Essentially low importance	s2	(ESLI)	(0.14,0.2,0.33)
Very low importance	s1	(VLI)	(0.11,0.14,0.2)
Absolutely low importance	s0	(ALI)	(0.11,0.11,0.14)

Step 2. Using the OWA operator, the fuzzy envelope for HFLTS is aggregated and built (Liu & Rodríguez, 2014). This aggregation gives a trapezoidal fuzzy number as a result.

Suppose the DMs' evaluations vary between two terms i.e. s_i and s_j. Then $s_0 \leq s_i < s_j \leq s_g$. The trapezoidal fuzzy membership function parameters A = (α,β,γ,δ) are calculated as follows:

$$\alpha = \min\{a_L^i, a_M^i, a_M^{i+1}, \dots, a_M^j, a_R^j\} = a_L^i \quad (4.25)$$

$$\delta = \max\{a_L^i, a_M^i, a_M^{i+1}, \dots, a_M^j, a_R^j\} = a_R^i \quad (4.26)$$

$$\beta = \begin{cases} a_M^i & if\ i+1=j \\ OWA_{w^2}\left(a_M^i, \ldots, a_M^{\frac{i+j}{2}}\right) & if\ i+j\ \ is\ even \\ OWA_{w^2}\left(a_M^i, \ldots, a_M^{\frac{i+j-1}{2}}\right) & if\ i+j\ \ is\ odd \end{cases} \tag{4.27}$$

$$\gamma = \begin{cases} a_M^{i+1} & if\ i+1=j \\ OWA_{w^1}\left(a_M^j, a_M^{j-1}, \ldots, a_M^{\frac{i+j}{2}}\right) & if\ i+j\ \ is\ even \\ OWA_{w^1}\left(a_M^j, a_M^{j-1}, \ldots, a_M^{\frac{i+j+1}{2}}\right) & if\ i+j\ \ is\ odd \end{cases} \tag{4.28}$$

OWA operation requires a weight vector. By using the parameter in the unit interval [0, 1], first and second type weights are defined.

The first type of weights $W^1 = (w_1^1, w_2^1, \ldots, w_n^1,)$ are defined as:

$$w_1^1 = \alpha_2,\ w_2^1 = \alpha_2 (1- \alpha_2),\ \ldots,\ w_n^1 = \alpha_2 (1- \alpha_2)^{n-2} \tag{4.29}$$

The second type of weights $W^2 = (w_1^2, w_2^2, \ldots, w_n^2,)$ are defined as:

$$w_1^2 = \alpha_1^{n-1},\ w_2^2 = (1- \alpha_1)\ \alpha_1^{n-1}, \ldots,\ w_n^2 = 1- \alpha_1 \tag{4.30}$$

where $\alpha_1 = \frac{g-(j-i)}{g-1}$, $\alpha_2 = \frac{(j-i)-1}{g-1}$ and g is the number of terms in the evaluation scale, j is the rank of highest evaluation and i is the rank of lowest evaluation value of the interval.

Step 3. The pairwise comparison matrix ($\tilde{C}$) which consists of the aggregated fuzzy numbers generated in Step 2 where $\widetilde{c_{ij}} = (c_{ijl}, c_{ijm1}, c_{ijm2}, c_{iju})$, is obtained. The reciprocal values are obtained as shown next:

$$\widetilde{c_{ij}} = \left(\frac{1}{ciju}, \frac{1}{cijm2}, \frac{1}{cijm1}, \frac{1}{cijl}\right) \tag{4.31}$$

Step 4. For each row ($\tilde{r}_i$) of the matrix $\tilde{C}$, fuzzy geometric mean is calculated using Eq. (4.32).

$$\tilde{r}_i = (\tilde{c}_{i1} \otimes \tilde{c}_{i2} \ldots \otimes \tilde{c}_{in})^{1/n} \tag{4.32}$$

Step 5. The fuzzy weight ($\tilde{w}_i^{CR}$) of each main factor of SWOT is computed with ($\tilde{r}_i$) values as shown below:

$$\tilde{w}_i^{CR} = \tilde{r}_i \otimes (\tilde{r}_1 \otimes \tilde{r}_2 \ldots \otimes \tilde{r}_n)^{-1} \tag{4.33}$$

Step 6. The fuzzy global weights of sub-factors of SWOT are calculated.

$$\tilde{w}_{ij}^{G} = \tilde{w}_i^{CR} \times \tilde{w}_j^{CR} \tag{4.34}$$

where $\tilde{w}_{ij}^{G}$ the global weight of sub-factors of SWOT.

Step 7. The trapezoidal fuzzy numbers $\tilde{w}_{ij}^{G}$ using Eq.(4.35) are defuzzified and the defuzzified values are normalized using Eq. (4.36).

$$w_{ij}^{G} = \frac{\alpha+2\beta+2\gamma+\delta}{6} \tag{4.35}$$

$$w_{ij}^{N} = \frac{w_{ij}^{G}}{\sum_i \sum_j w_{ij}^{G}} \tag{4.36}$$

Steps 1–5 are repeated for both the main and their sub-criteria. Overall sub-criteria weights are found by using steps 6-7.

5.3.2 HFL CODAS Method for Ranking

The steps of the proposed HFL CODAS method are presented as follows:

Step 1. Initially, the DMs evaluated the criteria and alternatives concerning each other by using the linguistic scale given in Table 5.1.

Step 2. Calculate the average fuzzy decision matrix ($\tilde{X}$) as follows:

$$\tilde{X}_l = [\tilde{x}_{ijl}]_{n \times m} \tag{4.37}$$

$$\tilde{X} = [\tilde{x}_{ij}]_{n \times m} \tag{4.38}$$

$$\tilde{x}_{ij} = \sum_{l=1}^{q} \tilde{x}_{ijl} \tag{4.39}$$

where $\tilde{x}_{ijl}$ represents fuzzy performance value of *i*th alternative with respect to *j*th criterion and *l*th DM, and $\tilde{x}_{ij}$ shows the average fuzzy performance value of *i*th alternative with respect to *j*th criterion.

Step 3. Fuzzy normalized decision matrix is determined by using the following equations:

$$\tilde{N} = [\tilde{n}_{ij}]_{n \times m} \tag{4.40}$$

$$\tilde{n}_{ij} = \begin{cases} \tilde{x}_{ij}/\max_i \mathfrak{D}(\tilde{x}_{ij}) & if\ j \in B \\ 1 - (\tilde{x}_{ij}/\max_i \mathfrak{D}(\tilde{x}_{ij}) & if\ j \in C) \end{cases} \tag{4.41}$$

where *B* and *C* denotes the sets of benefit and cost criteria. Moreover, the defuzzified value of o trapezoidal fuzzy number $\tilde{M} = (m_1, m_2, m_3, m_4)$ is determined as follows (Wang et al., 2006).

$$\mathfrak{D}(\tilde{x}_{ij}) = \frac{1}{3}\left(m_1 + m_2 + m_3 + m_4 - \frac{m_3 m_4 - m_1 m_2}{(m_3 + m_4) - (m_1 + m_2)}\right) \tag{4.42}$$

Step 4. Compute fuzzy weighted normalized matrix as follows:

$$\tilde{R} = [\tilde{r}_{ij}]_{n \times m} \tag{4.43}$$

$$\tilde{r}_{ij} = \tilde{w}_j \otimes \tilde{n}_{ij} \tag{4.44}$$

Step 5. Identify fuzzy negative-ideal solution with equation (4.45).

$$\widetilde{NS} = [\widetilde{ns}_j]_{l \times m} \tag{4.45}$$

$$\widetilde{ns}_j = \min_i \tilde{r}_{ij} \tag{4.46}$$

Step 6. The fuzzy weighted Euclidean (*ED_i*) and fuzzy weighted Hamming (*HDi*) distances of alternatives from fuzzy negative-ideal solution is calculated by using equation (4.47) and (4.48).

$$ED_i = \sum_{j=1}^{m} d_E(\tilde{r}_{ij}, \widetilde{ns}_j) \tag{4.47}$$

$$HD_i = \sum_{j=1}^{m} d_H(\tilde{r}_{ij}, \widetilde{ns}_j) \tag{4.48}$$

where d_E and d_H between two trapezoidal fuzzy numbers $\widetilde{M} = (m_1, m_2, m_3, m_4)$ and $\widetilde{N} = (n_1, n_2, n_3, n_4)$ are defined as follows (Li, 2007):

$$d_E(\widetilde{M}, \widetilde{N}) = \sqrt{\frac{(m_1-n_1)^2+2(m_2-n_2)^2+2(m_3-n_3)^2+(m_4-n_4)^2}{6}} \tag{4.49}$$

$$d_H(\widetilde{M}, \widetilde{N}) = \frac{|m_1-n_1|+2|m_2-n_2|+2|m_3-n_3|+|m_4-n_4|}{6} \tag{4.50}$$

Step 7. Relative assessment matrix (*RA*) is determined as follows:

$$RA = [p_{ik}]_{n\times n} \tag{4.51}$$

$$p_{ik} = (ED_i - ED_k) + (t(ED_i - ED_k) \times (HD_i - HD_k)) \tag{4.52}$$

where $k \in \{1,2,\ldots,n\}$ and t is a threshold function that is identified as follows:

$$t(x) = \begin{cases} 1 & if \quad |x| \geq \theta \\ 0 & if \quad |x| < \theta \end{cases} \tag{4.53}$$

DMs can set threshold the parameter (θ) of the function in the range of 0.01-0.05. In this study, we use $\theta = 0.02$.

Step 8. The assessment score (AS_i) of each alternative is calculated with equation (4.54).

$$AS_i = \sum_{k=1}^{n} p_{ik} \tag{4.54}$$

Step 9. According to the values of AS_i, alternatives are ranked.

5.3.3 HFL COPRAS Method for Ranking

The procedure of the COPRAS method includes the following steps:

Step 1. Initially, the DMs evaluated the criteria and alternatives concerning each other by using the linguistic scale given in Table 5.1.

Step 2. These linguistic expressions convert to trapezoidal fuzzy numbers by using fuzzy envelope (Liu & Rodríguez, 2014).

Step 3. The decision matrices composed of the HFS formed by the DMs are defuzzified into the crisp numbers with Eq. (4.35).

Step 4. Normalize the decision matrix using the following formula

$$\boldsymbol{x}_{\boldsymbol{ij}}^{*} = \frac{\boldsymbol{x}_{\boldsymbol{ij}}}{\sum_{\boldsymbol{i}=1}^{\boldsymbol{m}} \boldsymbol{x}_{\boldsymbol{ij}}} \qquad \text{for (j= 1,2, …,n)} \tag{4.55}$$

Step 5. Determine the weighted normalized decision matrix

$$d_{ij} = x_{ij}^{*} . w_j \tag{4.56}$$

The weighted normalized values are calculated by multiplying the weight of evaluation indicators w_j with normalized decision matrices.

Step 6. The sums S_i- and S_i+ of weighted standardized values are calculated using the following equations for both beneficial and non-beneficial criteria separately:

$$S_{i+} = \sum_{j=1}^{k} d_{ij} \tag{4.57}$$

$$S_{i-} = \sum_{j=k+1}^{n} d_{ij} \tag{4.58}$$

Step 7. The Q_i values are relative importance values for each alternative and are calculated using the equation (4.59). The result of the calculations is determined as the most appropriate alternative with the highest relative importance value.

$$Q_i = S_{i+} + \frac{\sum_{i=1}^{m} S_{i-}}{S_{i-} * \sum_{i=1}^{m} \frac{1}{S_{i-}}} \tag{4.59}$$

Step 8. The highest relative priority (Q_{max}) value is found.

Step 9. Calculate the performance index (P_i) of each alternative with this equation:

$$P_i = \left[\frac{Q_i}{Q_{max}}\right] \times 100\% \tag{4.60}$$

6. CASE STUDY

6.1 Background

The proposed method is illustrated through a real case to verify its usability. Smart cities in the world and Turkey have been a rapidly rising trend in recent years. Along with this developing trend, a firm named as 'ABC' plans to invest in the field of smart city in Istanbul. An investment in the smart city area is very extensive. So it was decided to go further and find a focus. Therefore, a smart city model has been established with literature review and expert opinions. Opinions were obtained from the experts of Istanbul Electricity Tramway and Tunnel Businesses (IETT) about the creation of the smart city model and where necessary for the evaluation approach. IETT is an institution that provides public transport services in Istanbul under the umbrella of Istanbul Metropolitan Municipality.

In the first phase of the application, the components determined to decide which area to focus on are evaluated with the proposed approach. In the second stage, HFL MCDM based SWOT analysis is applied to analyze the determined area and determine appropriate strategies.

6.2 Phase I: Evaluation of Proposed Smart City Model based on HFL MCDM

6.2.1 Proposed Smart City Model

The proposed smart city model with literature review and expert opinions is as in Table 6.1. This model consists of six main dimensions. These dimensions are smart economy, smart environment & energy, smart buildings & living, smart transportation, smart people and smart safety and governance.

Table 6.1a: Proposed Smart City Model

		MAIN DIMENSION					
		Smart economy	Smart environment & energy	Smart buildings & living	Smart transportation	Smart people	Smart safety and governance
COMPONENTS	Intelligent parking system				X		
	Car sharing services				X		
	Smart stop				X		
	Trafic cameras				X		
	Mixed-model access				X		
	Advanced passenger information systems				X		
	Multi-modality transportation				X		
	Lane management				X		
	Public transportation priority				X		
	Network safety				X		X
	Security and emergency systems				X		X
	Accessibility			X	X		X
	Individual safety				X		X
	Productivity	X	X	X	X		
	Entrepreneurship & innovation	X			X		X
	Local & global inter-connectedness	X					
	Flexibility of labour market	X					
	Resources management	X	X				
	Economic image & trademarks	X					
	Waste disposal		X				
	Sustainability		X	X	X		
	Intelligent watering systems		X				
	Energy efficiency		X				
	Ecological footprint		X				
	Renewable energy use		X	X			
	Green urban planning		X	X			
	Infrastucture status			X	X		

Table 6.1b: Proposed Smart City Model

	MAIN DIMENSION					
	Smart economy	Smart environment & energy	Smart buildings & living	Smart transportation	Smart people	Smart safety and governance
Smart counters			X			
Panic button					X	
Visually impaired navigation					X	
Chronic patient follow-up					X	
Tele-medicine					X	
Digital education					X	
Quality of life			X		X	
Online tickets and toursit cards					X	
Tourism information via Internet					X	
Culturally vbrant & happy					X	
Creativity					X	
Business ecosystem	X					X
Leadership and administrative structure						X
Transparency	X					X
Participation in decision-making						X
Financial profile	X					X
Smart traffic lights				X		
Individual assistant				X	X	

Smart economy: City economies constitute the basis of national economies. In order to make the economic structure of the country stronger, models to strengthen the city's economies should be studied. Each city should analyze its strengths and weaknesses while establishing its own economic models, and determine future opportunities. In order for cities to have sustainable and bright economic indicators ready for the future, it is necessary to have innovative, entrepreneurial, productive, labor-market flexible, internationally efficient city economic movements.

Smart economic movements embrace the concepts of intelligent growth, sustainable growth and inclusive growth. When the smart economy applications are examined all over the world, the concept of "Share Economy" attracts attention. Sharing economy is the name of the scheme that is used for the duration of your needs. It is a new micro economy model. With this new model, both the resources in idle state are being restored to the economy and the savings in the individual sense are ensured (IESE Cities in Motion Index, 2016).

Smart environment & energy: Smart Environment uses data collection from utility networks, users, and air, water, and other city resources in order to establish main areas of action in urban planning and cityinfrastructure planning as well as to inform urban services managers to achieve a more efficient and sustainable urban environment while improving the citizens' quality of life (ASCIMER,2017).

Smart energy provides deep insights about overall power consumption by buildings, commercials and residential. It helps in designing and executing various strategies to cut down power consumption. These days, few of the cities are using smart grids and smart streets. Even, smarts meters are also installed in the homes. Integration of IoT helps cities in optimizing power production, improving grid management, and providing effective distribution of energy production. On the other hand, the smart grid allows businesses to improve data capture, grid modernization, outage detection, field operations and disaster recovery techniques (Urban Hub, 2017).

The primary benefits of smart waste management lie in improving the efficiency of waste collection, pickup, separation, reuse and recycle. Waste disposal can be monitored to ensure it is being done in an environmentally friendly way, waste streams can be assessed and the appropriate recycling and disposal solutions implemented. Waste collection can be streamlined across the city reducing truck rolls. The overall efficiency and performance of waste collection can be continuously monitored. As the transport of waste from collection points to disposal/ recycle sites is optimized, this leads to less carbon emission and less transport loads on the city streets and roads (Deloitte, 2015).

Smart buildings & living: A smart building integrates the different physical systems present in a building (such as Building Automation System (BAS) - HVAC & Energy

Management, Lighting Control System, Fire & Life Safety Control Systems, Parking Guidance and Management Systems) in an intelligent manner way to ensure that all the different systems in a building act together in an optimized and efficient manner. This integration is typically done in a reliable, cost effective, and sustainable manner with a goal to provide optimal comfort and well-being for their occupants thereby enhancing productivity and performance.

Smart building management systems can improve building energy efficiency, reduce wastage, and ensure optimum usage of water with operational effectiveness and occupant satisfaction. Smart Living is considered the wise management of facilities, public spaces and services using ICT technologies to put focus on improving accessibility, on flexibility of uses, and on getting closer to the citizens´ needs (Kass, 2017).

Smart transportation: Smart Mobility pursues to offer the most efficient, clean and equitable transport network for people, goods and data. It leverages the available technologies to gather and provide information to users, planners and transport managers, allowing the reshaping of urban mobility patterns, of planning mechanisms and the enhancement of multimodality by improving the coordination and integration of different transportation modes (ASCIMER, 2017). It helps in reducing the traffic, easy movement of goods, and travel management for people. For example, smart traffic systems help citizens by reducing the chances of road accidents.

Additionally, it also helps in avoiding traffic jams, reducing pollution, and promoting a healthier life. Traditionally, ‘individual’ mobility in cities has been through some form of mechanized or motorized transport, mostly cars. There seems to be a movement away from cars towards transportation system design around individual mobility which feature bicycles, ridesharing (or carpooling), carsharing and more recently on-demand transport (Su, et al., 2011).

Smart people: A Smart City needs the citizen to participate in order for the incoming initiatives to succeed. The existence of citizens able to participate wisely in smart urban life and to adapt to new solutions providing creative solutions, innovation and diversity to their communities is needed. Education appears as the main tool to improve this dimension, as well as initiatives to retain creative profiles (ASCIMER, 2017).

“Smart Healthcare” refers to the provision of healthcare using intelligent and networked technologies, which help monitor the health conditions of citizens. It is enabling a shift in focus to prevention instead of cure - with a broader view of overall care, healthy living and wellness management. It is applicable for both in/out patient environments ensuring the availability of appropriate health care and resources at the right time. Smart healthcare systems are being used in both developed and developing nations (Lombardi, et al., 2012; Anand, 2017).

Smart safety and governance: Smart Government makes use of available technology to be aware of -and coordinate with the activities carried out by other municipalities, achieve synergies through collaborations with other stakeholders and reach out citizens’ needs in order to improve both, public services, and confidence in the public institutions (ASCIMER, 2017). Factors such as involvement of citizen in the planning and implementation processes of the public as well as private sector, local governments, non-governmental organizations and universities are important in achieving the success of smart city applications. Citizen-centric governments based on the understanding of building multi-faceted, collaborative cultures constitute the groundwork for management's cooperation with institutions, as well as the grounds for receiving citizens' ideas and contributions, when the successful smart city initiatives in the world are examined (Chourabi et al., 2012).

Criterion explanations are as follows:

- *Intelligent parking system:* With these systems, vehicles are directed to empty parking spaces (Easypark, 2017; Kass, 2017).
- *Car sharing services:* Common vehicle use services supported by new technologies, considering urban influences (Easypark, 2017; Urban Hub, 2017).
- *Smart stop:* Stations that can access the information of buses passing by, and can be loaded on transportation cards (Public Technology Platform, 2016).
- *Traffic cameras:* Systems that provide instant follow-up of the traffic situation (Alkan, 2015; Yılmaz, 2015).

- *Mixed-model access:* The transportation system can access and provide access to many models (Deloitte Report, 2015; Cohen, 2013).
- *Advanced passenger information systems:* These are systems that enable passengers to access all kinds of information (traffic situation, accident situation, travel route, etc.) in transportation (Yılmaz, 2015).
- *Multi-modality transportation:* Transport of the load or passenger using at least two modes of transport (Deloitte Report, 2015; ASCIMER, 2017).
- *Lane management:* The management of lanes with electronic systems is flexible in certain situations (Yılmaz, 2015).
- *Public transportation priority*: The traffic control settings are set to reduce the amount of time spent by public transport in traffic (Easypark, 2017; ASCIMER, 2017).
- *Network safety*: Roads, bridges and other infrastructure elements or any kind of network are robust and reliable (Alkan, 2015; ASCIMER, 2017).
- *Security and emergency systems*: These systems exist to detect and prevent incidents that require any kind of emergency interventions, especially traffic accidents, and to reduce the most (United Nations Commission, 2016).
- *Accessibility:* Systems are accessible by the user at any time (Giffinger & Gudrun, 2010; ASCIMER, 2017; Chourabi et al. 2012, United Nations Commission, 2016).
- *Individual safety*: Individuals in society can safely benefit from urban systems (Urban Hub, 2017; Giffinger & Gudrun, 2010).
- *Productivity*: The desired positive results are obtained from the applied new systems (Cohen, 2013; Ilıcalı et al., 2016; Giffinger & Gudrun, 2010; ASCIMER, 2017).
- *Entrepreneurship & Innovation*: New job opportunities with smart city concept (Cohen, 2013; Ilıcalı et al., 2016; Giffinger & Gudrun, 2010).
- *Local and global interconnectedness*: The economy is locally and globally connected (Cohen, 2013).
- *Flexibility of labor market*: It is a labor market where flexible recruitment opportunities are provided, recruitment is easy and recycling costs can be reduced (Ilıcalı et al., 2016; Giffinger & Gudrun, 2010; ASCIMER, 2017).

- *Resources management*: The effective management of existing resources (Deloitte Report, 2015; Ilıcalı et al., 2016; Giffinger & Gudrun, 2010).
- *Economic image & trademarks*: The economic presence of the city (Ilıcalı et al., 2016).
- *Waste disposal*: The disposal and recycling of wastes in a way that minimizes damage to the environment (Easypark, 2017; Kass, 2017).
- *Sustainability*: The existing system is designed to meet the needs of future generations (Deloitte Report, 2015).
- *Intelligent watering systems*: These systems monitor water quality, detect leaks, and perform preventive maintenance (Public Technology Platform, 2016; Yılmaz, 2015).
- *Energy efficiency*: Optimizing energy usage using intelligent systems (Ministry of Urban Development Government of India, 2015).
- *Ecological footprint*: Used to measure how many resources the world population demands from the ecosystem and how much it needs to be recycled (Deloitte Report, 2015; Ilıcalı et al., 2016).
- *Renewable energy usage*: The energy resources used are continuously re-usable with new technologies (Anand, 2017).
- *Green urban planning*: City planning is environmentally oriented (Easypark, 2017; Cohen, 2013).
- *Infrastructure status*: The state of the infrastructure that has been refreshed in the smart city (FORRESTER, 2010; Urban Hub, 2017; Kass, 2017).
- *Smart counters*: A tool that can measure how much electricity is consumed over time, integrated with new technologies (Public Technology Platform, 2016; Yılmaz, 2015).
- *Panic button*: With the buttons on it, voice and continuous communication can be made without using the handset with the call center officer. An emergency ambulance can be called in cases such as emergency health problems or home accidents (Public Technology Platform, 2016).
- *Visually impaired navigation*: Guidance of visual impairments by voice command (Public Technology Platform, 2016).

- *Chronic patient follow-up*: Chronic patients are monitored centrally by measuring the blood sugar, blood pressure and pulse rate (Public Technology Platform, 2016).
- *Tele-medicine*: It is a system that allows the views of radiological examinations to be accessed in 7x24 web environment and shared with citizens via e-pulse application (Ministry of Urban Development Government of India, 2015).
- *Digital education*: Advanced technologies exist in the education system (smart boards, etc.) (Cohen, 2013; Giffinger & Gudrun, 2010).
- *Quality of life:* (Ilıcalı et al., 2016; Chourabi et al. 2012; United Nations Commission, 2016).
- *Online tickets and tourist cards*: Tickets and cards that can be used at museum locations, purchased as special online for tourists (ASCIMER, 2017).
- *Tourism information via Internet*: Tourists can conduct their business online (ASCIMER, 2017; Su, et al., 2011).
- *Culturally vibrant & happy*: An individual who is happy in every sense of the word and the city he lives in (Cohen, 2013).
- *Creativity:* (Cohen, 2013; ASCIMER, 2017).
- *Business ecosystem*: Business opportunities and diversity in the city (Easypark, 2017).
- *Leadership and administrative structure*: The administrative structure of the city (FORRESTER, 2010).
- *Transparency*: To be clear in all processes in the innovations made (ASCIMER, 2017; United Nations Commission, 2016)
- *Participation in decision-making*: Including all stakeholders in decision-making and business processes (Giffinger & Gudrun, 2010).
- *Financial profile*: The financial situation of people living in a city (FORRESTER, 2010).
- *Smart traffic lights*: Traffic lights that direct voice commands, lights, drivers Giffinger & Gudrun, 2010).
- *Individual assistant*: These systems enable us to access any kind of information in transportation (Deloitte Report, 2015).

6.2.2. Weighting of Components with HFL SAW

The steps of the HFL SAW method for weighting of components are as follows:

Step 1. DMs evaluated criteria using linguistic terms in Table 5.1. These evaluations with linguistic expressions are shown in Table 6.2.

Table 6.2a: DMs Evaluation for Smart City Components

Components	DM1	DM2	DM3
Intelligent parking system	Greater than M	Between M and VH	Between L and M
Car sharing services	Between M and VH	Between L and M	Lower than M
Smart stop	Between L and M	Between M and VH	Lower than M
Trafic cameras	Between L and M	At least H	Between L and M
Mixed-model access	Greater than M	At least H	Between M and VH
Advanced passenger information systems	At least H	Between M and VH	Between M and VH
Multi-modality transportation	Greater than M	Greater than M	Between M and VH
Lane management	At least H	Lower than M	Between L and M
Public transportation priority	At least H	At least H	Between L and M
Network safety	Between M and VH	Greater than M	At least H
Security and emergency systems	Between M and VH	At least H	At least H
Accessibility	Between M and VH	At least H	Greater than M
Individual safety	Between M and VH	At least H	Greater than M
Productivity	Between M and VH	Between M and VH	Between L and M
Entrepreneurship & innovation	Between M and VH	Between L and M	Between L and M
Local and global interconnectedness	Lower than M	Between L and M	Between L and M
Flexibility of labour market	Between L and M	Between M and VH	At most L
Resources management	Between M and VH	At least H	Between M and VH
Economic image & trademarks	Between M and VH	At least H	Between L and M
Waste disposal	At least H	Between M and VH	Lower than M
Sustainability	Greater than M	Greater than M	Between M and VH
Intelligent watering systems	Between M and VH	Lower than M	Between L and M
Energy efficiency	At least H	At least H	Between L and M
Ecological footprint	At least H	Greater than M	Between L and M
Renewable energy use	Greater than M	Greater than M	Lower than M
Green urban planning	Between M and VH	Greater than M	Lower than M
Infrastucture status	Between M and VH	At least H	Lower than M
Smart counters	Between M and VH	Between L and M	Between M and VH
Panic button	Between L and M	Between L and M	Lower than M
Visually impaired navigation	Between M and VH	Between M and VH	Between M and VH
Chronic patient follow-up	Between L and M	Between L and M	Between L and M
Tele-medicine	Between M and VH	Between L and M	Between L and M
Digital education	Between M and VH	At least H	Between L and M
Quality of life	Greater than M	Greater than M	Between L and M
Online tickets and toursit cards	Between L and M	Between L and M	Between M and VH
Tourism information via Internet	Between L and M	Between M and VH	Between L and M

Table 6.2b: DMs Evaluation for Smart City Components

Components	DM1	DM2	DM3
Culturally vbrant & happy	Between M and VH	Between M and VH	Between L and M
Creativity	At least H	Between M and VH	Between L and M
Business ecosystem	Between M and VH	At least H	Between M and VH
Leadership and administrative structure	Between M and VH	At least H	Between L and M
Transparency	Between M and VH	Greater than M	Between L and M
Participation in decision-making	At least H	At least H	Between L and M
Financial profile	Greater than M	At least H	Between L and M
Smart traffic lights	Between M and VH	Between M and VH	At least H
Individual assistant	Between VL and L	Between M and VH	Between L and M

Step 2. Table 6.2 with linguistic hesitant expressions is transformed to HFLTS by using equations (4.13) - (4.18). The HFLTS are transformed into fuzzy numbers by using scale given in Table 5.1.

Step 3. Based on these numbers, the fuzzy weights of individual attributes are calculated by (4.21). The defuzzified values of the aggregated fuzzy weights are computed using (4.22) and the normalized weights of components are calculated using (4.23). Table 6.3 shows the weights of components.

Table 6.3a: Weights of Smart City Components

Components	**Defuzzified Weights**	**NORMALIZED WEIGHTS**	**RANK**
Intelligent parking system	0.583	0.0232	18
Car sharing services	0.417	0.0165	39
Smart stop	0.417	0.0165	39
Trafic cameras	0.528	0.0210	26
Mixed-model access	0.694	0.0276	1
Advanced passenger information systems	0.638	0.0253	14
Multi-modality transportation	0.694	0.0276	1
Lane management	0.473	0.0188	33
Public transportation priority	0.639	0.0254	8
Network safety	0.694	0.0276	1
Security and emergency systems	0.694	0.0276	1
Accessibility	0.694	0.0276	1
Individual safety	0.694	0.0276	1
Productivity	0.528	0.0209	27
Entrepreneurship & innovation	0.473	0.0188	33
Local and global interconnectedness	0.362	0.0144	44
Flexibility of labour market	0.417	0.0165	39
Resources management	0.638	0.0253	14
Economic image & trademarks	0.583	0.0232	18

Table 6.3b: Weights of Smart City Components

Components	**Defuzzified Weights**	**NORMALIZED WEIGHTS**	**RANK**
Waste disposal	0.528	0.0209	29
Sustainability	0.694	0.0276	1
Intelligent watering systems	0.417	0.0165	39
Energy efficiency	0.639	0.0254	8
Ecological footprint	0.639	0.0254	8
Renewable energy use	0.583	0.0232	18
Green urban planning	0.528	0.0209	29
Infrastucture status	0.528	0.0209	29
Smart counters	0.528	0.0209	29
Panic button	0.362	0.0144	44
Visually impaired navigation	0.583	0.0231	25
Chronic patient follow-up	0.418	0.0166	38
Tele-medicine	0.473	0.0188	33
Digital education	0.583	0.0232	18
Quality of life	0.639	0.0254	8
Online tickets and toursit cards	0.473	0.0188	33
Tourism information via Internet	0.473	0.0188	33
Culturally vbrant & happy	0.528	0.0209	27
Creativity	0.583	0.0232	18
Business ecosystem	0.638	0.0253	14
Leadership and administrative structure	0.583	0.0232	18
Transparency	0.583	0.0232	18
Participation in decision-making	0.639	0.0254	8
Financial profile	0.639	0.0254	8
Smart traffic lights	0.638	0.0253	14
Individual assistant	0.417	0.0165	39
	25.193	1.0000	

According to HFL SAW method results, the most appropriate factors are mixed-model access, multi-modality transportation, network safety, security and emergency systems, accessibility, individual safety and sustainability.

6.2.3. Prioritization of Main Dimensions with HFL Method

Step 1. Expert opinion has been used for the evaluation of the relationship matrix between smart city main dimensions and components in Table 6.1. DMs evaluated this matrix using linguistic terms in Table 5.1. One of these evaluations with linguistic expressions is shown in Table 6.4.

Table 6.4a: Evaluation of DM1

		MAIN DIMENSION					
		Smart economy	Smart environment & energy	Smart buildings & living	Smart transportation	Smart people	Smart safety and governance
COMPONENTS	Intelligent parking system				Greater than M		
	Car sharing services				Between M and VH		
	Smart stop				Between L and M		
	Trafic cameras				Between L and M		
	Mixed-model access				Greater than M		
	Advanced passenger information systems				Greater than M		
	Multi-modality transportation				Greater than M		
	Lane management				At least H		
	Public transportation priority				At least H		
	Network safety				Between M and VH		Between M and VH
	Security and emergency systems				Between M and VH		Between M and VH
	Accessibility			Between M and VH	Between M and VH		Between M and VH
	Individual safety				Between M and VH		Between M and VH
	Productivity	Between M and VH	Between M and VH	Between M and VH	Between M and VH		
	Entrepreneurs hip & innovation	Between M and VH			At least H		Between M and VH
	Local and global interconnected ness	Lower than M					
	Flexibility of labour market	Between L and M					
	Resources management	Between M and VH	Between M and VH				

Table 6.4b: Evaluation of DM1

	MAIN DIMENSION					
	Smart economy	Smart environment & energy	Smart buildings & living	Smart transportation	Smart people	Smart safety and governance
Economic image & trademarks	Between M and VH					
Waste disposal		At least H				
Sustainability		Greater than M	Greater than M	Greater than M		
Intelligent watering systems		Between M and VH				
Energy efficiency		At least H				
Ecological footprint		At least H				
Renewable energy use		Greater than M	Greater than M			
Green urban planning		Between M and VH	Between M and VH			
Infrastucture status			Between M and VH	Between M and VH		
Smart counters			Between M and VH			
Panic button					Between L and M	
Visually impaired navigation					Between M and VH	
Chronic patient follow-up					Between L and M	
Tele-medicine					Between M and VH	
Digital education					Between M and VH	
Quality of life			Greater than M		Greater than M	
Online tickets and toursit cards					Between L and M	
Tourism information via Internet					Between L and M	
Culturally vbrant & happy					Between M and VH	
Creativity					At least H	

Table 6.4c: Evaluation of DM1

	MAIN DIMENSION					
	Smart economy	Smart environment & energy	Smart buildings & living	Smart transportation	Smart people	Smart safety and governance
Business ecosystem	Between M and VH					Between M and VH
Leadership and administrative structure						Between M and VH
Transparency	Between M and VH					Between M and VH
Participation in decision-making						At least H
Financial profile	At least H					Greater than M
Smart traffic lights				Between L and M		
Individual assistant				Between L and M	Between L and M	

Step 2. Table 6.4 with linguistic hesitant expressions is transformed to HFLTS by using equations (4.13) - (4.18). The HFLTS are transformed into fuzzy numbers by using scale given in Table 5.1.

Step 3. The three separate values from the DMs were aggregated with (4.21) and then multiplied by the component weights obtained by the HFL SAW method. The defuzzified values of the aggregated fuzzy weights are computed using (4.35).

Ultimately, smart transportation has become the most important main dimensions among six alternatives with the final performance value of 0.271; while smart safety and governance, smart people, smart environment & energy, smart economy and smart buildings & living have positioned at the second, third, fourth, fifth and sixth ranks with 0.156, 0.123, 0.121, 0.115 and 0.102 as the final performance values, respectively.

6.3 Phase II: SWOT Analysis of Smart Transportation based on HFL MCDM

6.3.1. SWOT Analysis of Smart Transportation in Istanbul

As a starting point, a literature review is conducted on the subject and methods. Because of these studies, we decided to apply SWOT analysis in Istanbul to be able to handle all aspects of smart transportation. All the strengths, weaknesses, opportunities and threats for smart transportation in Istanbul are determined by the group of experts. These factors include 5 strengths, 5 weaknesses, 5 opportunities and 5 threats factors. The identified SWOT factors of smart transportationare listed in Table 6.5.

Table 6.5: SWOT Factors of Smart Transportation

Strengths:
S1: The existence of a population structure that can easily adopt new technologies S2: The presence of entrepreneurial capacity in smart transportation S3: Common and modern communication infrastructure S4: The speed of being an information society for Turkey S5: Investments in the information sector
Weaknesses:
W1: Lack of integration between government and institutions W2: Lack of common terminology and standards of smart transportation W3: Lack of specialized personnel in institutions W4: Inadequate AR-GE work and incentives W5: Inadequate domestic production in terms of software and hardware for smart transportation
Opportunities:
O1: Increased mobility in business O2: Increased awareness of energy efficiency and environmental protection 03: Turkey's geographical proximity to non-advanced markets in smart transportation applications O4: Still developing smart vehicle technology O5: The birth of new business areas with the development of smart transportation
Threats:
T1: High costs of smart transport applications T2: The continuation of the global financial crisis and the problems of the country's economy T3: External dependence on smart transport technologies T4: Globalization and increasing international competition T5: The expectation of individual motor mobility to exceed infrastructure capacities within 20 to 40 years

6.3.2. Identification of SWOT Factors Importance Degrees by HFL AHP

Step 1. In the first stage, the DMs evaluated the criteria with regards to each other by using the linguistic scale given in Table 5.2. Table 6.6 shows the pairwise comparisons of the main SWOT factors, filled by the DMs' evaluations using HFTLS. Table 6.7 present the pairwise comparisons of the strength sub-factors of SWOT. The other sub-factors were constructed as in Table 6.6.

Table 6.6: DMs's Evaluation of the main SWOT factors

DM1	Strengths	Weaknesses	Opportunities	Threats
Strengths	EE	Between ELI and EHI	Between ESLI and ELI	Between ELI and EHI
Weaknesses		EE	Between ELI and EHI	EE
Opportunities			EE	Between EHI and ESHI
Threats				EE

DM2	Strengths	Weaknesses	Opportunities	Threats
Strengths	EE	Between ESLI and ELI	Between ELI and EHI	Between ESLI and ELI
Weaknesses		EE	Between EHI and WHI	EE
Opportunities			EE	Between ELI and EHI
Threats				EE

DM3	Strengths	Weaknesses	Opportunities	Threats
Strengths	EE	Between EHI and ESHI	EE	Between EHI and ESHI
Weaknesses		EE	Between WLI and EE	EE
Opportunities			EE	Between EHI and ESHI
Threats				EE

Table 6.7: DMs's Evaluation of the strength sub-factors

DM1	S1	S2	S3	S4	S5
S1	EE	Between ELI and EHI	Between ELI and EHI	Between ELI and EHI	Between ESLI and ELI
S2		EE	EE	EE	Between ELI and EHI
S3			EE	EE	Between ELI and EHI
S4				EE	Between ELI and EHI
S5					EE

DM2	S1	S2	S3	S4	S5
S1	EE	Between EHI and ESHI	Between WHI and ESHI	Between EHI and ESHI	Between ELI and EHI
S2		EE	Between EHI and ESHI	EE	Between ESLI and ELI
S3			EE	Between WLI and EE	Between VLI and ESLI
S4				EE	Between ESLI and ELI
S5					EE

DM3	S1	S2	S3	S4	S5
S1	EE	Between EHI and ESHI	Between EHI and ESHI	EE	EE
S2		EE	EE	Between WLI and EE	Between WLI and EE
S3			EE	Between WLI and EE	Between WLI and EE
S4				EE	EE
S5					EE

Step 2. Calculate the one decision matrix X by aggregating the opinions of DMs $(\tilde{X}^1, \tilde{X}^2, \ldots, \tilde{X}^k)$; $X = [x_{ij}]$, where $x_{ij} = [s_{p_{ij}}, s_{q_{ij}}]$ where (Beg & Rashid, 2013)

$$s_{p_{ij}} = min\left\{\min_{l=1}\left(maxH_{s_{ij}}^{l}\right), \max_{l=1}\left(minH_{s_{ij}}^{l}\right)\right\} \tag{4.61}$$

$$s_{q_{ij}} = max\left\{\min_{l=1}\left(maxH_{s_{ij}}^{l}\right), \max_{l=1}\left(minH_{s_{ij}}^{l}\right)\right\}. \tag{4.62}$$

Aggregated decision matrix is shown in Table 6.8 and steps 2 are repeated for sub-criteria.

Table 6.8: Aggregated decision matrix for main criteria

	Strengths	**Weaknesses**	**Opportunities**	**Threats**
Strengths	EE	between ELI and EHI	between ELI and EE	between ELI and EHI
Weaknesses		EE	between EE and EHI	EE
Opportunities			EE	Between ELI and EHI
Threats				EE

Step 3. These linguistic expressions in Table 6.8 are transformed to trapezoidal fuzzy numbers with fuzzy envelope by using the OWA operator and the equations (4.25)-(4.31) for the main factors. Geometric means and weights of each criterion are calculated by using equations (4.32) and (4.33). Table 6.9 shows the normalized weights of the main factors of SWOT.

Table 6.9: Pairwise comparison values and normalized weights of the main criteria

	Strengths	**Weaknesses**	**Opportunities**	**Threats**	**Normalized Weights**
Strengths	(1,1,1,1)	(0.3,1,1,3)	(0.33,1,1,1)	(0.3,1,1,3)	(0.063,0.250,0.250,0.739)
Weaknesses	(0.3,1,1,3)	(1,1,1,1)	(1,1,1,3)	(1,1,1,1)	(0.109,0.250,0.250,0.739)
Opportunities	(1,1,1,3)	(0.33,1,1,1)	(1,1,1,1)	(0.3,1,1,3)	(0.083,0.250,0.250,0.739)
Threats	(0.3,1,1,3)	(1,1,1,1)	(0.3,1,1,3)	(1,1,1,1)	(0.083,0.250,0.250,0.739)

Step 4. Step 3 is repeated for the sub-criteria to obtain relative scores reported in Table 6.10. Equations (4.34), (4.35), (4.36) are applied to calculate the global scores, as well as the defuzzified weights and normalized weights of the sub-criteria, as given in Table 6.10.

Table 6.10: Normalized weights of sub-criteria

Sub-factors	Relative scores	Global scores	Defuzzified weights	Normalized weights
S1	(0.094,0.189,0.255,0.616)	(0.006,0.047,0.064,0.455)	0.114	0.046
S2	(0.075,0.189,0.205,0.446)	(0.005,0.047,0.051,0.330)	0.089	0.036
S3	(0.046,0.120,0.165,0.288)	(0.003,0.030,0.041,0.213)	0.060	0.024
S4	(0.075,0.189,0.205,0.288)	(0.005,0.047,0.051,0.213)	0.069	0.028
S5	(0.117,0.235,0.255,0.821)	(0.007,0.059,0.064,0.607)	0.143	0.058
W1	(0.032,0.108,0.232,0.923)	(0.003,0.027,0.058,0.682)	0.143	0.058
W2	(0.027,0.134,0.172,0.485)	(0.003,0.033,0.043,0.358)	0.086	0.035
W3	(0.050,0.154,0.247,0.891)	(0.005,0.039,0.062,0.659)	0.144	0.059
W4	(0.087,0.256,0.450,1.564)	(0.010,0.064,0.113,1.157)	0.253	0.103
W5	(0.029,0.134,0.171,0.604)	(0.003,0.034,0.043,0.446)	0.100	0.041
O1	(0.067,0.197,0.199,0.754)	(0.006,0.049,0.050,0.558)	0.127	0.052
O2	(0.054,0.197,0.199,0.566)	(0.004,0.049,0.050,0.419)	0.104	0.042
O3	(0.105,0.242,0.251,0.605)	(0.009,0.061,0.063,0.448)	0.117	0.048
O4	(0.067,0.197,0.199,0.705)	(0.006,0.049,0.050,0.521)	0.121	0.049
O5	(0.025,0.158,0.159,0.511)	(0.002,0.040,0.040,0.378)	0.090	0.037
T1	(0.057,0.210,0.268,1.177)	(0.005,0.053,0.067,0.870)	0.186	0.076
T2	(0.71,0.172,0.264,1.177)	(0.006,0.043,0.066,0.870)	0.182	0.074
T3	(0.057,0.214,0.365,1.010)	(0.005,0.053,0.091,0.747)	0.174	0.071
T4	(0.031,0.124,0.170,0.464)	(0.003,0.031,0.043,0.343)	0.082	0.034
T5	(0.022,0.088,0.170,0.372)	(0.002,0.022,0.043,0.275)	0.068	0.028
			2.450	1

At the end of the HFL AHP method, the factors' weights are calculated. The most important factor is found to be the "Inadequate AR-GE work and incentives (W4)", the second important one being "High costs of smart transport applications (T1)" and the third ranked factor is "The continuation of the global financial crisis and the problems of the country's economy (T2)".

6.3.3. Developing Strategies for Smart Transportation

According to HFL AHP results, the most important sub-factor of each SWOT main factor has been identified. The most important strength factor is "Investments in the information sector (S5)". The most important weakness factor is "W4: Inadequate AR-GE work and incentives (W4)". The most important opportunity factor is "Increased mobility in business (O1)" and the most important threat factor is "High costs of intelligent transport applications (T1)".

Strategies that are created with literature review and expert opinions according to these factors are as in Table 6.11.

Table 6.11: Strategies of Smart Transportation

	S5: Investments in the information sector	W4: Inadequate AR-GE work and incentives
O1: Increased mobility in business	**SO Strategies:** Sustainable Development Strategy (STR1)	**WO Strategies:** Competitive smart transport strategy (STR2) Strategy for increasing security and privacy (STR3)
T1: High costs of intelligent transport applications	**ST Strategies:** Transport innovation strategy (STR4)	**WT Strategies:** Planning and integrating strategy (STR5) Access facilitation strategy (STR6)

Sustainable Development Strategy (STR1): In simple terms, sustainable development means integrating the economic, social and environmental objectives of society, in order to maximise human well-being in the present without compromising the ability of future generations to meet their needs. This means seeking mutually supportive approaches whenever possible, and making trade-offs where necessary. The pursuit of sustainable development thus requires improving the coherence and complementarity of policies across a wide range of sectors, to respond to the complex development challenges ahead.

Sustainable transport must be viewed and integrated as an essential ingredient in sustainable development strategies. Transport infrastructure lasts for decades, which means that the decisions that the local and national governments make today will have long-lasting impacts on urban development and form, as well as climate (Giffinger & Gudrun, 2010; Forrester, 2010)

Competitive smart transport strategy (STR2): The main purpose of this strategy is to increase the awareness of users and practitioners of smart transportation systems. To this end, awareness-raising and promotion activities should be disseminated through public, private and civil society collaborations (Ilıcalı et al.). Opening of the external market of the information and communication technology industry will provide a strong position in the competitive environment. Local production should be encouraged on the basis of software and hardware used within the scope of smart transportation system. In order to be successful in a competitive environment, the number of qualified personnel should be increased and AR-GE activities should be carried out in smart vehicle technologies (T. C. Ministry of Transport, 2014).

Strategy for increasing security and privacy (STR3): This strategy focuses on the regulation of smart transport systems in the existing transport and communications infrastructure. With this strategy, traffic management in urban and inter-city road network is brought up effectively and efficiently. In transport, e-payment systems are disseminated. User information activities are developed. Fleet management practices are widespread and the system is developed in different levels to increase traffic safety in all transport systems (T. C. Ministry of Transport, 2014).

Transport innovation strategy (STR4): Transport innovation strategy includes analysis of the regional context and potential for innovation. It set up a sound and inclusive governance structure, production of a shared vision about the future of the region, selection of a limited number of priorities for regional development, establishing of suitable policy mixes and integration of monitoring and evaluation mechanisms (Condeco-Melhorado et al., 2015). Clean, efficient, safe, quiet and smart road vehicles, aircraft, vessels, rail vehicles are components of this strategy. With this strategy, the infrastructures will be renewed to fit the latest technology and intelligent, green, low-maintenance and climate-resilient infrastructure will be used.

Planning and integrating strategy (STR5): First, smart transport system architecture should be established at the national level. Along with this strategy, organizational arrangements are carried out in order to ensure the systematic planning, coordination and implementation of the intelligent transport system. The implementation of legislative arrangements for the implementation and integration of the intelligent transport system is among the foundations of this strategy (Ilıcalı et al.)

Access facilitation strategy (STR6): The availability of the system is important for effectiveness and efficiency. The transport infrastructure should be organized to provide more effective and safe services for the elderly, children and the disabled. At the same time, public transportation fleets must be regulated to provide more efficient (T. C. Ministry of Transport, 2014).

6.3.4. Strategies' Ranking by HFL CODAS

The CODAS method based on HFLTS was used to select the most appropriate strategy for smart transportation with respect to the factors determined in earlier steps.

Step 1. Initially, the DMs evaluated the criteria and alternatives about each other by using the linguistic scale given in Table 5.1. Table 6.12 shows the evaluation matrix of the sub-factors and alternatives, filled by the DM1's evaluation using HFLTS.

Table 6.12a: DM1's Evaluation Matrix

Strategies	S1	S2	S3	S4	S5
STR1	Between M and VH	Between M and VH	Greater than M	Lower than M	Lower than M
STR2	At least H	At least H	At least H	At least H	At least H
STR3	At most L	At most L	At most L	At most L	At most L
STR4	Greater than M	Greater than M	Greater than M	Greater than M	Greater than M
STR5	Between L and M	Between L and M	Between L and M	Between L and M	Between L and M
STR6	Between L and M	Between L and M	Between L and M	Between L and M	Between L and M

Strategies	W1	W2	W3	W4	W5
STR1	Lower than M	Lower than M	Between M and VH	Between M and VH	Between M and VH
STR2	At least H	At least H	At least H	At least H	At least H
STR3	At most L	At most L	At most L	At most L	At most L
STR4	Greater than M	Greater than M	Greater than M	Greater than M	Greater than M
STR5	Between L and M	Between L and M	Between L and M	Between L and M	Between L and M
STR6	Between L and M	Between L and M	Between L and M	Between L and M	Greater than M

Table 6.12b: DM1's Evaluation Matrix

Strategies	O1	O2	O3	O4	O5
STR1	Between M and VH	Between L and M	Between L and M	Between M and VH	Between M and VH
STR2	At least H	Lower than M	Between M and VH	At least H	At least H
STR3	At most L	Between L and M	Between L and M	At most L	At most L
STR4	Greater than M	Greater than M	Between L and M	Greater than M	Greater than M
STR5	Between L and M	Lower than M	Lower than M	Between L and M	Between L and M
STR6	Greater than M	Between L and M	Between L and M	Between L and M	Between L and M

Strategies	T1	T2	T3	T4	T5
STR1	Between M and VH	Lower than M	Between M and VH	Greater than M	Between M and VH
STR2	At least H	At least H	At least H	At least H	At least H
STR3	At most L	At most L	At most L	At most L	At most L
STR4	Greater than M	Greater than M	Greater than M	Greater than M	Greater than M
STR5	Between L and M	Between L and M	Between L and M	Between L and M	Between L and M
STR6	Between L and M	Between L and M	Between L and M	Between L and M	Greater than M

Step 2. These HFLTSs in Table 6.12 are transformed to trapezoidal fuzzy numbers with fuzzy envelope using the OWA operator and the equations (4.25)-(4.31). These fuzzy numbers are aggregated with the equations (4.37)-(4.39).

Step 3. The decision matrix is defuzzified into the crisp numbers with Eq. (4.42). It is normalized using equations (4.40)-(4.41) and the weighted normalized decision matrix with equations (4.43)-(4.44) is determined.

Step 4. The values of negative ideal solution, the fuzzy weighted Euclidean (ED_i) and fuzzy weighted Hamming (*HDi*) distances of alternatives were calculated using equations (4.45)-(4.50) and these values given as Table 6.13.

Table 6.13: Euclidean and Hamming Distances

ED1	0.3564	HD1	0.3563
ED2	0.5255	HD2	0.5255
ED3	0.0405	HD3	0.0402
ED4	0.5252	HD4	0.5252
ED5	0.1921	HD5	0.1919
ED6	0.2779	HD6	0.2777

Step 5. Relative assessment matrix (*RA*) is calculated with equations (4.51)-(4.53). Moreover, the assessment score (AS_i) of each alternative is computed with (4.54). Table 6.14 shows the final results.

Table 6.14: The Final Results of HFL CODAS

	A1	A2	A3	A4	A5	A6	Sum	Rank
STR1	0	-0.338	0.632	-0.338	0.329	0.157	0.442	3
STR2	0.338	0.000	0.970	0.000	0.667	0.495	2.471	1
STR3	-0.316	-0.970	0.000	-0.970	-0.303	-0.475	-3.034	6
STR4	0.338	0.000	0.970	0.000	0.666	0.495	2.468	2
STR5	-0.164	-0.667	0.303	-0.666	0.000	-0.172	-1.366	5
STR6	-0.078	-0.495	0.475	-0.495	0.172	0.000	-0.422	4

In accordance with results in Table 6.14, the most appropriate strategy is “Competitive smart transport strategy (STR2)”. The second, third, fourth, fifth and sixth alternatives are ranked as “Transport innovation strategy (STR4)”, “Sustainable Development Strategy (STR1)”, “Access facilitation strategy (STR6)”, “Planning and integrating strategy (STR5)” and “Strategy for increasing security and privacy (STR3)”, respectively.

6.3.5. Strategies’ Ranking by HFL COPRAS

The COPRAS method based on HFLTS was used to select the most appropriate strategy for smart transportation with respect to the factors determined in earlier steps. Step 1 and Step 2 of CODAS are applied again.

Step 1. The decision matrix is defuzzified into the crisp numbers with Eq. (4.35). It is normalized using equation (4.55) and the weighted normalized decision matrix with equation (4.56) is determined.

Step 2. The values of *Qi*, *Si+*, *Si-*, *Pi* were calculated using equations (4.57)-(4.60). Table 6.15 shows the final results.

Table 6.15: The Final Results of HFL COPRAS

	Si-	*Si+*	*Qi*	*Pi*	Ranking
STR1	1.748	1.727	3.229	92.978	6
STR2	2.155	2.038	3.256	93.755	5
STR3	1.099	1.084	3.473	100.000	1
STR4	2.098	2.187	3.438	99.011	2
STR5	1.348	1.380	3.328	95.833	3
STR6	1.551	1.584	3.276	94.345	4

In accordance with results in Table 6.15, the most appropriate strategy is “Strategy for increasing security and privacy (STR3)”. The second, third, fourth, fifth and sixth alternatives are ranked as “Transport innovation strategy (STR4)”, “Planning and integrating strategy (STR5)”, “Access facilitation strategy (STR6)”, “Competitive smart transport strategy (STR2)”, and “Sustainable Development Strategy (STR1)”, respectively.

6.4 Obtained Results and Discussion

In this master thesis, case study with two phases is applied. In the first phase of the study, components of the proposed smart city model are weighted by the HFL SAW method. According to HFL SAW method results, mixed-model access, multi-modality transportation, network safety, security and emergency systems, accessibility, individual safety and sustainability components are the most appropriate factors.

After that, the most appropriate main dimension in proposed smart city model is obtained with HFL method and this is smart transportation dimension with the final performance value of 0.271; while other main dimensions have positioned with 0.156, 0.123, 0.121, 0.115 and 0.102, respectively.

In the second phase, SWOT factors of smart transportation in Istanbul are determined with literature review and expert opinions. The weights of each SWOT factor are calculated with HFL AHP method. At the end of the HFL AHP method, the most important factor is found to be the “Inadequate AR-GE work and incentives (W4)”.

Then, strategies are determined considering the most important of each SWOT factor. These strategies are evaluated with HFL CODAS and HFL COPRAS methods. According to HFL CODAS method, the most appropriate strategy is “Competitive smart transport strategy (STR2)”. The second, third, fourth, fifth and sixth alternatives are ranked as “Transport innovation strategy (STR4)”, “Sustainable Development Strategy (STR1)”, “Access facilitation strategy (STR6)”, “Planning and integrating strategy (STR5)” and “Strategy for increasing security and privacy (STR3)”, respectively.

To see difference between CODAS and COPRAS methods, HFL COPRAS is applied for the evaluation of same strategies. According to HFL COPRAS method, the most appropriate strategy is “Strategy for increasing security and privacy (STR3)”. The second, third, fourth, fifth and sixth alternatives are ranked as “Transport innovation strategy (STR4)”, “Planning and integrating strategy (STR5)”, “Access facilitation strategy (STR6)”, “Competitive smart transport strategy (STR2)”, and “Sustainable Development Strategy (STR1)”, respectively. The results vary according to the basic characteristics of the techniques.

7. CONCLUSION AND PERSPECTIVES

The most obvious characteristic of the age that we are in is the rapid change. The formation of societies that can keep up with the rapid changes of the age is directly related to the sustainable and high welfare-level environments. In recent years, many countries have begun to build urban infrastructures and services to raise the welfare level of communities and to manage growth and development in a sustainable way. Smart cities are based on the idea of restructuring cities that maximize the efficiency for people and nature. Smart cities aim for human-focused, strategic, environment-friendly management approach, service areas, and increased living standards.

People have to choose between alternatives in almost every period of their lifetime. In the case of decision-making, it is essential to choose the most appropriate one from a variety of alternatives that may be possible according to the circumstances and circumstances available to achieve an aim.

MCDM methods have been developed for solving such problems since decision problems with a large number of criteria and alternatives are complex. In real world decision-making problems, it is difficult to decide when there are not many criteria and sufficient information. The mixed structure of the smart cities evaluation involves many various and contradictory criteria. However, it is difficult to decide on, and rank smart cities when information is of uncertain nature. Sometimes DMs have difficulties to express their thoughts by numbers because these quantitative values are far from their own way of thinking in daily life. Furthermore, DMs can express their opinions more comfortably with words, instead of crisp numbers. The HFLTS overcomes the uncertainty of this MCDM problem.

In the first phase of the study, the importance degree of the smart city model components was taken from DMs and components are weighted by the HFL SAW method. Relationship matrix between main dimensions and components is constructed by collecting linguistic data from DMs and most appropriate main dimension in proposed smart city model is obtained. This is smart transportation dimension. According to the smart transportation concept, SWOT factors of smart transportation in Istanbul are determined with literature review and expert opinions in second phase. HFL AHP method is used to define the final relative weights and priority factors. Then, strategies are determined considering the most important of each SWOT factor with HFL CODAS and HFL COPRAS methods.

The objective of this study is to develop a new smart city model and propose staretegic analysis of smart transportation in smart city concept using the HFL MCDM methods, which will give a closer result to your daily life. This study will show how verbal information is effective for MCDM and how HFL methods which is a rare method in the literature, results in the case of hesitancy.

In summary, the main contributions of this thesis are:

- to propose new smart city model.
- to propose the evaluation of this smart city model with HFL methods.
- to propose a quantitative basis in SWOT analysis with integrated HFL MCDM methods such as HFL AHP, HFL CODAS and HFL COPRAS.
- to propose integrated SWOT analysis for smart transportation strategy selection for the first time.

The proposed evaluation methodology as well as its application to a real case study has also contributions to the practical field by providing guidance to the managers who seek the most appropriate strategies for smart transportation.

For future research, the problem can be defined with aggregation operator for GDM to aggregate DMs' evaluations. This aggregation operator can be the ordered weighted hesitant fuzzy weighted averaging (OWHFWA) operator, the ordered weighted hesitant fuzzy weighted geometric (OWHFWG) operator, the ordered weighted generalized hesitant fuzzy weighted averaging (OWGHFWA) operator etc.

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