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-RESEARCH ARTICLE-

A MULTI-CRITERIA DECISION-MAKING MODEL FOR RANKING SMART MEGACITIES AND DEFINING THEIR KEY PERFORMANCE INDICATORS

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Abstract

The aim of this study was to develop an integrated and innovative approach to facilitate the ranking of evaluation criteria used to assess and compare smart megacities (SMCs). The methodology used to design the approach was based on Criteria Importance through CRITIC and CODAS. In this method, the degree of importance of each item of the criteria affecting the concept of a smart city was determined by CRITIC, an objective weighting method. Then, megacities can be compared using the CODAS technique to determine the extent to which they have adopted smart city concepts. In the current study, 32 SMCs were compared in four main areas and 20 subcategories. An analysis of the order of importance given to each area found that mobility and activities (0.32) was highest, followed closely by health and safety (0.313), opportunities (0.198), and governance (0.168). The subcategories with the greatest weight were the availability of a website/application that enables citizens to easily donate surplus items (0.076), online information about traffic conditions (0.073), and online access to job opportunities (0.062). In addition, it was determined that the most successful megacities applying the smart city concept are Beijing and Hangzhou. This study has the potential to be considered a pioneer in the literature in terms of the proposed methodology for an empirical evaluation to support smart megacity planning.

Keywords: *Smart City, Multi-Criteria Analysis, Key Indicators, Information and Communication Technology, Sustainability.*

JEL Codes: *C60, 030.*

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AKILLI MEGA ŞEHİRLERİN SIRALANMASI VE TEMEL PERFORMANS GÖSTERGELERİNİN TANIMLAMASI İÇİN ÇOK KRİTERLİ BİR KARAR VERME MODELİ [2]

Öz

Bu çalışmanın amacı, akıllı mega şehirlerin (AMŞ) karşılaştırılmasını ve değerlendirme kriterlerinin sıralanmasını kolaylaştırmak için entegre ve yenilikçi bir yaklaşım geliştirmektir. Yaklaşımı tasarlamak için kullanılan metodoloji, CRITIC ve CODAS tekniklerine dayanmaktadır. Bu yöntemde akıllı şehir kavramını etkileyen kriterlerin her bir maddesinin önem derecesi objektif bir ağırlıklandırma yöntemi olan CRITIC ile belirlenmiştir. Daha sonra, akıllı şehir kavramlarını ne ölçüde benimsediklerini belirlemek için CODAS tekniği kullanılarak mega şehirler karşılaştırılmıştır. Mevcut çalışmada, 32 AMŞ 4 ana alanda ve 20 alt kategoride karşılaştırıldı. Analize göre önem sırasısı en yüksek kriter mobilite ve aktivite (0.32) iken, onu sağlık ve güvenlik (0.313), fırsatlar (0.198) ve yönetişim (0.168) takip etmektedir. En fazla ağırlığa sahip alt kategoriler, vatandaşların fazla eşyalarını kolayca bağışlayabilmelerini sağlayan bir web sitesi/uygulaması (0.076), trafik durumu hakkında çevrimiçi bilgi (0,073) ve iş fırsatlarına çevrimiçi erişim (0.062) olmuştur. Ayrıca akıllı şehir konseptini uygulayan en başarılı mega şehirlerin Pekin ve Hangzhou olduğu belirlenmiştir. Bu çalışma, akıllı şehir planlamasını desteklemek için önerilen ampirik bir değerlendirme metodolojisi olması açısından literatürde öncü sayılma potansiyeline sahiptir.

Anahtar Kelimeler: *Akıllı Şehir, Çok Kriterli Analiz, Temel Göstergeler, Bilgi ve İletişim Teknolojileri, Sürdürülebilirlik.*

JEL Kodları: *C60, 030.*

"Bu çalışma Araştırma ve Yayın Etiğine uygun olarak hazırlanmıştır."

1. INTRODUCTION

A smart city is a municipality that aims to use resources more efficiently, improve the quality of life of its citizens, and achieve sustainability through innovative technology. Designing smart cities focuses on modern and dynamic infrastructures to promote economic development and ensure environmental protection (Pellicer et al., 2013). The goal is to integrate technology into the city's physical infrastructure for more effective resource management and improved living standards (Mallapuram et al., 2017). Smart cities not only improve the functioning of the city through technology, but also promote sustainable development (Lim et al., 2019). Adopting the smart city concept entails conscious investments in high-tech communications, sustainability, and improved quality of life for its citizens by providing dynamic and safe environments.

[2] Genişletilmiş Türkçe Özet, makalenin sonunda yer almaktadır.

In recent years, the migration of a significant part of the world's population to urban areas and the consequent increase in demand for resources and facilities has inevitably led to many new problems, such as inadequate infrastructure, traffic congestion, and air pollution (Cui & Cao, 2022). These rapidly growing cities must also confront other urgent problems regarding resource consumption, security, and social cohesion. Urbanization and population growth put greater pressure on the existing infrastructure, causing uncontrolled resource use and excessive energy consumption (Milošević et al., 2019).

Rapid urbanization necessitates the continuous development of initiatives and technologies to provide better service to the public (Wu & Chen, 2021). To minimize the problems caused by rapid growth, governments must develop innovative methods (Chiroli et al., 2022) and adopt new urban planning, development, and management strategies (Piciroagă et al., 2018). In megacities, defined as urban areas with a population greater than 10 million, the effects of population growth appear more intensely. To overcome urban problems in megacities, which play an important role in economy, science, technology, and politics, the concept of the smart megacity should be adopted and its implementation formulated.

The adoption and practical application of the SMC concept will bring many benefits for citizens and administrators. The concept ensures the integration of innovative solution alternatives into daily life, economic development and increasing the quality of life. Thus, a modern model that provides economic development and sustainability based on dynamic infrastructures will be represented. This will pave the way for the spread of innovative and modern city concepts that provide sustainable development. Reliable, objective, and comprehensive methodologies must be developed to guide cities through the process of designing a smart city. The system is complex (Albino et al., 2015) and requires a multicriteria assessment to address often contradictory situations. Multicriteria decision-making consists of a set of steps to structure and shape decision making (Chiroli et al., 2022) at all stages of smart city projects (Hoang et al., 2019). The limited number of studies available in the literature have tended to use subjective weighting methods, such as AHP and Delphi (Ozkaya & Erdin, 2020). However, subjective weighting can be affected by differing perceptions of the experts, causing the relationships between indicators to be misrepresented (Wu et al., 2009).

The current study formulated a structured model integrating CRITIC and CODAS to compare smart megacities (SMCs). In the study, the degree of importance of the criteria affecting the concept of a smart city is determined by CRITIC, which is an objective weighting method. Then, the megacities were compared according to the extent of their adoption of smart city concepts using the CODAS technique. To the best of our knowledge, this represents a pioneering study in the literature in terms of the proposed methodology and the evaluation of the subject from a megacity perspective. It aims to present effective, objective, and reliable findings so that the data collected can guide the adoption of smart city technology. In addition, the smart features of megacities will be explored and the current situation of the cities sampled will be revealed to provide a better idea about the development path.

During the implementation phase, 32 SMCs were analysed considering four main areas and 20 subcategories. The analysis ranked these areas in level of importance as first mobility and activities (0.32), then health and safety (0.313), opportunities

(0.198), and governance (0.168). The subcategories with the highest criterion weights were the availability of a website/application that allows citizens to easily donate their surplus items (0.076) and facilitating online ticket purchase for shows and museums (0.073). The review of existing smart megacities found that the most successful are Beijing (1.761) and Hangzhou (1.755).

1.1. Literature Review

Especially in the 2000s, economic globalization resulted in significant urban changes. The emergence of global cities led to the restructuring of the world city system, and the concept of the megacity emerged (Yeh et al., 2015). A megacity is defined as a city centre or city with a population greater than 10 million. Rapid urbanization and the growth of cities and megacities is particularly evident in developing countries (Akiyode, 2010).

The effects of globalization on a regional scale necessitated the development of megacity regions (Cui et al., 2023). However, due to overgrowth, it is clear that megacities have developed a unique set of management problems. Rapid urbanization causes concerns about many issues, such as environment and security (Lundqvist et al., 2003). Recently, academics and policy makers have paid special attention to the increase in the number of megacities, the rapid growth of existing megacities, and the problems caused by this growth. Researchers strive to find ways to mitigate the effects of rapid urbanization and expanding urban centres.

Efforts to improve the cities of the future, rapid advances in technology, and the increasing level of globalization have led to the emergence of a new urban community concept—the smart city. 2022). There are numerous contradictions among the experts regarding a clear explanation of the concept of a smart city (Milošević et al., 2019). The main reason for the lack of a universally accepted definition is that researchers have focused on different dimensions of the concept. In the definitions in the literature, the dimensions generally emphasized are innovation, technology, sustainability and efficiency.

Implementing a smart city is a strategy that aims to improve the quality of life of citizens living in urban areas by applying innovation and technology to solve the problems created by high population density (Zapolskytė et al., 2020). According to a similar definition, a smart city is an interdisciplinary field of study that aims to use resources more efficiently, improve the quality of life of citizens, and provide environmental benefits (Picioroagă et al., 2018). Barrionuevo, Berrone, and Ricart (2012) defined the concept of a smart city as the intelligent and coordinated application of all available technology and resources to develop integrated, viable, and sustainable city centres.

The adoption and implementation of the smart city model will provide many benefits for both citizens and governments. The concept ensures that current innovative solutions are incorporated into the daily activities of cities, increasing economic growth and quality of life. Smart cities represent a modern concept that promotes economic development based on dynamic infrastructures, improving quality of life, and ensuring sustainability (Pellicer et al., 2013). Smart cities improve the functioning of cities through the use of information and communication technologies (Camero &

Alba, 2019) and represent an innovative city model that provides sustainable development (Lim et al., 2019).

The smart city concept, which has strategic effects on enhancing quality of life, sustainability, and economic growth, has been examined in many studies in the literature. Gouveia, Seixas, and Giannakidis (2016) presented an analytical framework to address energy deficiencies in smart cities and to handle scattered data. Picioroagă, Eremia, and Sănduleac (2018) developed a key performance indicator system for smart cities focusing on energy and environmental issues and evaluated the performances of cities through AHP. Rondini et al. (2018) presented a multicriteria approach for the selection and rating of smart city product–service systems.

Büyüközkan and Mukul (2019) tested an integrated model in which quality function deployment and fuzzy SAW approaches are used together to evaluate smart city logistics solutions. Charalabidis and Theocharopoulou (2019) proposed a decision support model to select best-practice interventions for smart cities from the perspective of citizens' opinions and municipal policies. Milosevic et al. (2019) presented a holistic approach based on expert opinions to determine the priority order of the main indicators and activities in the concept of a smart city.

Sisman and Aydinoglu (2020) presented an approach using geographic information systems–based decision-making techniques in sustainable land management practices in smart cities. Using the AHP technique, Urfalı and Eymen (2020) determined the criteria affecting the settlement of regions where the smart intersection system will be applied in smart cities. Zapolskytė, Burinskienė, and Trépanier (2020) proposed an approach based on the AHP technique to compare smart-city mobility system indicators and infrastructures, which they classified into five groups.

Hajduk (2021), using the TOPSIS technique, evaluated cities in Poland from the smart-city perspective. Rani (2021) proposed a wildfire prediction model for smart cities based on a multicriteria approach that incorporated wildfire risks into the city's resilience plan. Wu and Chen (2021) developed a structured approach for selecting smart city projects using Delphi and AHP methods. Tadic et al. (2022) evaluated various strategies in line with expert opinions to identify applicable Industry 4.0 technologies and create smart sustainable city logistics solutions. In the current literature, there are few systematic case studies on the development of smart megacities using complex evaluation methods. Therefore, the current study proposes an integrated methodology to identify critical success factors for smart megacities and compare relevant cities..

2. METHODOLOGY

In the current study, an integrated approach based on CRITIC and CODAS techniques is proposed for the comparison of smart megacities, and the CRITIC method is used to determine the critical success factors for smart cities. CRITIC is a technique developed to obtain the objective weights of criteria in decision-making problems (Diakoulaki et al., 1995) and has been widely used to weight criteria in many practical applications (Krishnan et al., 2021). In the CRITIC method, which uses standard deviations and correlations, both the contrast intensity of the criteria and the contradictions between criteria are taken into account (Rani et al., 2021). The method provides more effective results compared to other objective weighting methods that only consider contrast intensity. The basic principle of the CRITIC technique is that if the scores of a criterion differ more from one alternative to the next, this criterion should provide more meaningful information (Zhu et al., 2020).

After determining the levels of importance of the criteria, the CODAS method was used to rank smart megacities. CODAS is a decision-making approach based on calculations that is used to evaluate various alternatives, taking into account the distances of the alternatives from the negative ideal solution and considering the criteria with different measurement units (Ghorabaee et al. 2016). Euclidean and Taxicab distances are taken into account according to distance from the negative ideal solution (Badi et al., 2018). The technique is based on the assumption that an alternative that is farther from the negative ideal solution will be more attractive (Ghorabaee et al., 2016). The 11-step approach proposed in the study is presented below.

Step 1. The decision matrix (DM) is created as specified in Equation (1).

$$X = \begin{matrix} A_1 \\ A_2 \\ \cdots \\ A_4 \end{matrix} \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{12} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

Step 2. Normalized values (r_{ij}) are found using Equation (2) for cost-type criteria and Equation (3) for benefit-type criteria. Thus, the DM is transformed into a normalized DM.

$$r_{ij} = \frac{x_j^{max} - x_{ij}}{x_j^{max} - x_j^{min}} \tag{2}$$

$$r_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}} \tag{3}$$

Step 3. Linear correlation coefficients (ρ_{jk}) are obtained using Equation (4), and thus the correlation matrix is created.

$$\rho_{jk} = \frac{\sum_{i=1}^{m}(r_{ij}-\overline{r_j})(r_{ik}-\overline{r_k})}{\sqrt{\sum_{i=1}^{m}(r_{ij}-\overline{r_j})^2 \sum_{i=1}^{m}(r_{ik}-\overline{r_k})^2}} \tag{4}$$

Step 4. C_j values highlighting the total information contained in the criteria are obtained through Equations (5) and (6).

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{m}(r_{ij}-\overline{r_j})^2}{m-1}} \tag{5}$$

$$C_j = \sigma_j \sum_{k=1}^{n}(1 - \rho_{jk}) \tag{6}$$

Step 5. The importance degrees (w_j) of the evaluation criteria are calculated using Equation (7).

$$w_j = \frac{C_j}{\sum_{k=1}^{n} C_j} \tag{7}$$

Step 6. After the criterion weights are found, the alternatives are ranked using the CODAS technique. For this, the values in the initial decision matrix are converted to normalized values ($\hat{r}_{ij}$) according to the CODAS technique. At this stage, Equation (8) is used for cost type criteria, and Equation (9) is used for benefit type criteria.

$$\hat{r}_{ij} = \frac{\min_i x_{ij}}{x_{ij}} \tag{8}$$

$$\hat{r}_{ij} = \frac{x_{ij}}{\max_i x_{ij}} \tag{9}$$

Step 7. The normalized DM values created according to the CODAS technique are multiplied by the criterion weights obtained in Step 5 by means of Equation (10), and the weighted DM is obtained.

$$\tilde{r}_{ij} = w_j \hat{r}_{ij} \tag{10}$$

Step 8. The negative ideal solution is identified by determining the smallest performance value (n_{sj}) in each column of the weighted DM (Equations (11) and (12)).

$$n_s = [n_{sj}]_{1xm} \tag{11}$$

$$n_{sj} = \min_i \tilde{r}_{ij} \tag{12}$$

Step 9. The Euclidean (E_i) and Taxicab (T_i) distances from the negative ideal solution are calculated for each alternative using Equations (13) and (14).

$$E_i = \sqrt{\sum_{j=1}^{m} (\tilde{r}_{ij} - ns_j)^2} \tag{13}$$

$$T_i = \sum_{j=1}^{m} |\, \tilde{r}_{ij} - ns_j| \tag{14}$$

Step 10. Using Equations (15) and (16), the relative evaluation matrix (R_a) is created. The value of ψ found in Equation (16) is a threshold value that defines the Euclidean distance of the two alternatives and is defined in Equation (17). The τ value in Equation (17) is a threshold parameter determined by the decision makers. The threshold parameter is a value between 0.01 and 0.05 and specifies the degree of insignificance of the Euclidean distance. If the difference between the Euclidean distances of the two alternatives is greater than τ, the ψ value is accepted as 1, and both Euclidean and Taxicab distances are taken into account. However, if the difference between the Euclidean distances is less than the threshold parameter, only the Euclidean distance is taken into account.

$$R_a = [h_{ik}]_{nxn} \tag{15}$$

$$h_{ik} = (E_i - E_k) + ((\psi(E_i - E_k) \text{ x } (T_i - T_k)) \tag{16}$$

$$\psi(x) = \begin{cases} 1 \; eğer |E_i - E_k| \geq \tau \\ 0 \; eğer |E_i - E_k| < \tau \end{cases} \tag{17}$$

Step 11. The evaluation scores (H_i) of the alternatives are calculated via Equation (18).

$$H_i = \sum_{k=1}^{n} h_{ik} \tag{18}$$

3. RESULTS

In the current study, 32 SMCs were compared based on four main dimensions and 20 subcategories, as shown in Table 1. Cities subject to analysis are listed as Bangkok (A_1), Beijing (A_2), Bengaluru (A_3), Bogota (A_4), Buenos Aires (A_5), Cairo (A_6), Chengdu (A_7), Chongqing (A_8), Delhi (A_9), Guangzhou (A_{10}), Hangzhou (A_{11}), Ho Chi Minh City (A_{12}), Hyderabad (A_{13}), Istanbul (A_{14}), Jakarta (A_{15}), Lagos (A_{16}), London (A_{17}), Los Angeles (A_{18}), Manila (A_{19}), Mexico City (A_{20}), Moscow (A_{21}), Mumbai (A_{22}), New York (A_{23}), Osaka (A_{24}), Paris (A_{25}), Rio de Janeiro (A_{26}), Sao Paulo (A_{27}), Seoul (A_{28}), Shanghai (A_{29}), Shenzhen (A_{30}), Tianjin (A_{31}) ve Tokyo (A_{32}).

Table 1. Main Criteria and Sub-Criteria Used in The Research

Main Criteria	Sub-Criteria
Health & Safety (C_1)	Quick online reporting of city repair problems (C_{11})
	Website/application allowing citizens to donate surplus items (C_{12})
	Free public Wi-Fi (C_{13})
	Security cameras for citizens' safety (C_{14})
	Website/application reporting levels of air pollution (C_{15})
	Online medical appointments (C_{16})
Mobility & Activities (C_2)	Car sharing apps (C_{21})
	Apps that guide you to an available parking spot (C_{22})
	Bicycle rental services (C_{23})
	Online information facilitating the use of public transport (C_{24})
	Online information about traffic conditions (C_{25})
	Online ticket purchasing for events and museums (C_{26})
Opportunities (C_3)	Online access to job opportunities (C_{31})
	Good teaching of information technology in schools (C_{32})
	Online services to facilitate starting a business (C_{33})
	Current internet speed and reliability to meet connection needs (C_{34})
Governance (C_4)	Online public access to city finance (C_{41})
	Online voting to increase participation (C_{42})
	Online platforms where citizens can propose ideas (C_{43})
	Online processing of identity documents (C_{44})

The steps followed in the implementation process are given below.

Step 1. Thirty-two megacities were analysed according to four main criteria and 20 subcategories. The DM obtained in this study is presented in Appendix 1.

Step 2. Using Equation (3), the normalization process is applied, and a normalized DM is created according to the CRITIC technique (Appendix 2).

Step 3. The correlation coefficients of the criteria are obtained through Equation (4), and the correlation matrix presented in Appendix 3 is created.

Step 4. First, the σ_j values of the criteria are calculated using Equation (5); then the correlation coefficients are subtracted from 1 and the value 1-ρ_{jk} is obtained. Finally,

the C_j values of the evaluation criteria are obtained using Equation (6). The C_j values of the criteria are presented in Appendix 4.
Step 5. The importance ranking of the evaluation criteria is calculated using Equation (7), and the criteria weights are obtained (Appendix 4). Accordingly, the criteria weights for the main criteria are listed as 0.313, 0.32, 0.198 and 0.168.
Step 6. The values in the DM given in Appendix 1 are converted to normalized values according to the CODAS technique, using Equation (9), which was used for all criteria since they are of the benefit type. The normalized DM according to the CODAS technique is given in Appendix 5.
Step 7. The normalized DM values created according to the CODAS technique and the criterion weights are multiplied using Equation (10), and the weighted DM presented in Appendix 6 is created.
Step 8. Negative ideal solutions are determined by identifying the least effective performance value for each criterion in the weighted DM.
Step 9. Euclidean distances of the alternatives to the negative ideal solution are obtained using Equation (13), and Taxicab distances are obtained using Equation (14) (Appendix 7).
Step 10. Using Equations (15) and (16), a relative evaluation matrix is created. In the present study, the threshold parameter τ was accepted as 0.02.
Step 11. The evaluation scores of the alternatives are obtained using Equation (18) (Appendix 8). As calculated, the most effective alternatives in the current application are A_2 and A_{11}. Accordingly, the most successful megacities in the smart city sample are Beijing and Hangzhou.

4. DISCUSSION

Today, the rapid growth of cities and megacities has led to a decline in the quality of life in urban settlements and the emergence of a series of new challenges. As a consequence, the smart city concept, designed to promote sustainable development while taking into account the needs of its citizens, has gained acceptance in city management to address the problems of rapid urbanization. In this process, the development of reliable, objective, and comprehensive quantitative approaches to guide the development of smart cities is a strategic research topic. With the original and quantitative approach proposed in the present study, it is aimed to contribute to the adoption and implementation of the SMC concept. Thus, it is aimed to indirectly contribute to the integration of innovative solution alternatives into daily life and increase the quality of life of citizens. The spread of the SMC concept will ensure the spread of innovative city models that provide sustainable development. City concepts based on dynamic city infrastructures and based on economic development and sustainability will be adopted.
This study proposes a multicriteria application model that enables the ranking of the importance of various evaluation criteria for SMCs and allows these cities to be compared. The proposed model aims to identify the most critical criteria for an SMC and to allow city planners to assess their current situation in relation to their counterparts. An evaluation model based on the CRITIC and CODAS techniques was applied to highlight critical areas for smart megacities and to obtain cities' profiles.

To clarify the strategic factors in the model, the importance levels of the criteria were determined using the CRITIC method, and then the CODAS technique was applied to determine the success levels of megacities. In the application, four main areas and 20 subcategories were selected. These criteria were taken into consideration in order to evaluate the smart city application of 32 megacities.
The analysis ranked the importance of the major areas as mobility and activities (0.32), health and safety (0.313), opportunities (0.198), and governance (0.168) in implementing SMCs. The subcategories with the greatest weights were website/application to facilitate citizens in donating their surplus items (0.076), online information about traffic conditions (0.073), and online access to job opportunities (0.062). Studies in the literature have shown that urban transportation efficiency is the most important aspect of smart cities (Hajduk, 2021). City managers should provide strategies to increase citizens' use of mobility services and ensure the availability of applications that provide accurate and up-to-date schedules and route information of public conveyances, such as metros and buses. Likewise, innovative online platforms should be created that share information about parking and traffic conditions.
Another dimension that was highly ranked in importance was health and safety. In this area, administrators should maximize their interaction with their citizens, create platforms where citizens can communicate their problems, and respond promptly to them. Possible maintenance and repairs in the city should be announced by means of SMS and mail, and applications and websites should be created to keep abreast of these activities. A technological security infrastructure should be created that makes citizens feel safe from the threat of accidents or crime. Finally, free Wi-Fi services should be offered to the public in key locations in the city.
The subcategory with the highest ranking of importance was a website/application that assists citizens in easily donating their surplus items. In today's world, in which income and consumption inequities are increasing rapidly, people want to help those in need. However, citizens have a trust problem as to whether the people they help are really in need or whether the aid they give really reaches the hands of those in need. To that end, public institutions can build greater confidence in the public by linking the needy with the benevolent on an electronic platform. Another important subcategory was providing online information about traffic jams. In megacities, traffic congestion can be problematic at any time, and the ability of local governments to direct citizens to avoid congested areas before they set off is clearly beneficial. In addition, the criterion referring to online access to job opportunities was heavily weighted. In local governments with many employees, citizens should be kept informed of job opportunities and apprised of the number of people and the qualifications sought by the municipality through an application with up-to-date postings. Thus, citizens can benefit from knowing about job opportunities and be confident that city management functions openly and without favouritism.

CONCLUSION

Based on the results of the explanatory case study of SMCs, some practical contributions and theoretical implications have been obtained, which can be summarized as follows. First, a structured and hybrid model is proposed that can help public agency managers evaluate smart city projects. Findings that will contribute to the concept are presented by developing a methodology for developing an effective strategy for a sustainable smart city. Information has been gathered that can guide the detection of deficiencies in the implementation of smart systems and assist decision makers in reviewing improvements in citizens' well-being. In addition, the proposed methodology facilitates the comparison of smart cities and the evaluation of the smartness level of one's own city. Similarly, a decision process can be created for local administrators to select applicable strategies. Furthermore, the obtained results, proposed strategies, and key indicators can form the basis for further research to be conducted in future studies.

The theoretical implications obtained in the present study include the development of an objective weighting method to evaluate smart cities. Subjective weighting methods cannot avoid the bias of human input and may not reflect the obvious influence of certain indicators, whereas the CRITIC method presented is an objective criterion weighting technique that offers an integrated and innovative approach based on two techniques. With the proposed approach, the existing smart-city literature will be enriched. Its hybrid decision-making system more easily determines the areas where resource investment is needed, and a systematic comparison of cities can be performed.

In future studies, the proposed model can be tested on different city groups. In addition, subjective techniques can be tested by local administrators or an expert panel using decision data. A sample from various segments of the population can be recruited, and the effect levels of the factors can be verified using structural equation modelling. Comparing the results of such studies with the current findings is a potential research topic that will contribute to the literature. Accordingly, different quantitative techniques can be proposed and tested to characterize the current, important, and dynamic concept of smart cities.

AKILLI MEGA ŞEHİRLERİ SIRALAMAK VE TEMEL PERFORMANS GÖSTERGELERİNİ TANIMLAMAK İÇİN BİR ÇOK KRİTERLİ KARAR VERME MODELİ

1. GİRİŞ

Akıllı bir şehir tasarlama sürecinde karar vericilere rehberlik edilmesi için güvenilir, objektif ve kapsamlı metodolojiler geliştirilmelidir. Karmaşık ve çelişkili durumları ele almak, çok kriterli bir değerlendirme gerektirmektedir. Çok kriterli karar verme, akıllı şehir projelerinin tüm aşamalarında karar vermeyi yapılandırmak ve şekillendirmek için bir dizi adımdan oluşmaktadır. Literatürde bulunan sınırlı sayıdaki çalışmalar, AHP ve Delphi gibi sübjektif ağırlıklandırma yöntemlerini kullanma eğiliminde olmuştur. Ancak sübjektif ağırlıklandırma yöntemleri, uzmanların farklı algılarından etkilenerek göstergeler arasındaki ilişkilerin yanlış sunulmasına neden olabilme potansiyeline sahiptir.

Mevcut çalışmada, akıllı mega şehirleri (AMŞ) karşılaştırmak için CRITIC ve CODAS'ı entegre eden yapılandırılmış bir model önerilmiştir. Çalışmada akıllı şehir kavramını etkileyen kriterlerin önem derecesi objektif bir ağırlıklandırma yöntemi olan CRITIC ile belirlenmiştir. Daha sonra akıllı şehir konseptlerini benimseme derecelerine göre mega şehirler CODAS tekniği kullanılarak karşılaştırılmıştır. Çalışma, önerilen metodoloji ve konunun mega kent perspektifinden değerlendirilmesi açısından literatürde öncü bir araştırmadır. Toplanan verilerin akıllı şehir teknolojisinin benimsenmesine rehberlik edebilmesi için etkili, objektif ve güvenilir bulgular sunulması amaçlanmaktadır. Ayrıca mega kentlerin akıllı özellikleri araştırılacak ve örneklenen kentlerin mevcut durumu ortaya konulacaktır.

2. YÖNTEM

Mevcut çalışmada, AMŞ'leri karşılaştırılması için CRITIC ve CODAS tekniklerine dayalı bütünleşik bir yaklaşım geliştirilmiştir. Akıllı şehirler için kritik başarı faktörlerinin belirlenmesinde CRITIC yöntemi kullanılmıştır. CRITIC, karar verme problemlerinde kriterlerin nesnel ağırlıklarını elde etmek için geliştirilmiş bir tekniktir ve birçok pratik uygulamada kriterleri ağırlıklandırmak için yaygın olarak kullanılmaktadır.

Kriterlerin önem dereceleri belirlendikten sonra AMŞ'leri sıralamak için CODAS yöntemi kullanılmıştır. CODAS, alternatiflerin negatif ideal çözüme olan uzaklıklarını dikkate alarak ve kriterleri farklı ölçüm birimleriyle dikkate alarak çeşitli alternatifleri değerlendirmek için kullanılan bir karar verme yaklaşımıdır. Mevcut araştırmada 11 adımdan oluşan bir metodoloji önerilmiştir.

3. BULGULAR

Uygulama aşamasında, 4 ana kriter ve 20 alt kriter dikkate alınarak 32 şehir analiz edilmiştir. Ana kriterler önem derecelerine göre mobilite ve aktivite (0.32), sağlık ve güvenlik (0.313), fırsatlar (0.198) ve yönetişim (0.168) biçiminde sıralanmaktadır. Kriter ağırlıklarının en yüksek olduğu alt kategoriler vatandaşların fazla eşyalarını kolayca bağışlayabilmelerini sağlayan bir web sitesi/uygulaması (0.076), trafik durumu hakkında çevrimiçi bilgi (0.073) ve iş fırsatlarına çevrimiçi erişim (0.062) olmuştur. Mevcut şehirlerin gözden geçirilmesi sonucunda, en başarılı olanların Pekin (1.761) ve Hangzhou (1.755) olduğu tespit edilmiştir.

4. TARTIŞMA

Analiz sonucunda kriter ağırlığı en yüksek olan ana kriterin mobilite ve aktivite olduğu tespit edilmiştir. Literatürdeki çalışmalar, kentsel ulaşım verimliliğinin akıllı şehirlerin en önemli yönü olduğunu göstermiştir. Şehir yöneticileri, vatandaşların mobilite hizmetlerini kullanmasını artıracak stratejiler sağlamalı ve metro / otobüs gibi toplu taşıma araçlarının doğru ve güncel çizelgelerini ve güzergah bilgilerini sağlayan uygulamaların kullanılabilirliğini sağlamalıdır. Aynı şekilde, park etme ve trafik durumu hakkında bilgi paylaşan yenilikçi çevrimiçi platformlar oluşturulmalıdır.

Önem sıralamasında ikinci sırada çıkan ana kriter sağlık ve güvenliktir. Bu alanda yöneticiler vatandaşlarıyla etkileşimlerini en üst düzeye çıkarmalı, vatandaşların sorunlarını iletebileceği platformlar oluşturmalı ve vatandaşlara anında yanıt vermelidir. Şehirdeki olası bakım ve onarımlar SMS ve posta yoluyla duyurulmalı, bu faaliyetlerden haberdar olmak için aplikasyonlar ve web siteleri oluşturulmalıdır. Vatandaşların kaza veya suç tehdidinden kendilerini güvende hissetmelerini sağlayan teknolojik bir güvenlik altyapısı oluşturulmalıdır. Ayrıca, şehrin kilit noktalarında halka ücretsiz Wi-Fi hizmetleri sunulmalıdır.

Önem sıralaması en yüksek olan alt kriter vatandaşların ihtiyaç fazlası eşyalarını kolayca bağışlamalarına yardımcı olan web sitesi/uygulama olmuştur. Gelir ve tüketim eşitsizliklerinin hızla arttığı günümüz dünyasında insanlar ihtiyaç sahiplerine yardım etmek istemektedir. Ancak vatandaşlar, yardım ettikleri kişilerin gerçekten ihtiyaç sahibi olup olmadığı veya yaptıkları yardımların gerçekten ihtiyaç sahiplerinin eline ulaşıp ulaşmadığı konusunda bir güven sorunu yaşamaktadır. Bu amaçla kamu kurumları, ihtiyaç sahiplerini hayırseverlerle elektronik ortamda buluşturarak kamuoyunda daha fazla güven oluşturabilir. Bir diğer önem derecesi yüksek alt kriter ise trafik sıkışıklığı hakkında çevrimiçi bilgi sağlamaktır. Mega şehirlerde trafik sıkışıklığı önemli bir sorundur ve yerel yönetimler vatandaşları yola çıkmadan önce sıkışık alanlardan uzak durmaları yönünde yönlendirmelidir. Bununla birlikte, iş fırsatlarına çevrimiçi erişime atıfta bulunan kriter önem derecesi açısından üçüncü sıradadır. Çok sayıda çalışanı olan yerel yönetimlerde vatandaşlara, iş imkanları ve belediyenin aradığı nitelikler hakkında güncel ilanların yer aldığı bir uygulama ile bilgi verilmesi sağlanmalıdır. Böylece vatandaşlar, iş fırsatlarından yararlanabilir ve şehir yönetiminin açık ve kayırmacılık olmaksızın işlediğinden emin olabilir.

SONUÇ

Bu çalışmada elde edilen teorik çıkarımlar, akıllı şehirleri değerlendirmek için objektif bir ağırlıklandırma yönteminin geliştirilmesini içermektedir. Sübjektif ağırlıklandırma yöntemleri, bireyin yanlılığını önleyemez ve belirli göstergelerin bariz etkisini yansıtmayabilir. Uygulamada kullanılan CRITIC yöntemi, entegre ve yenilikçi bir yaklaşım sunan objektif bir kriter ağırlıklandırma tekniğidir. Önerilen yaklaşım ile mevcut akıllı şehir literatürü zenginleştirilecektir. Geliştirilen sistem ile kaynak yatırımı gereken alanlar daha kolay belirlenmekte ve şehirlerarası sistematik bir karşılaştırma yapılabilmektedir.

Gelecekteki çalışmalarda, önerilen model farklı şehir grupları üzerinde test edilebilir. Ayrıca, nüfusun çeşitli kesimlerinden oluşturulan bir örneklem ile faktörlerin etki düzeyleri, yapısal eşitlik modellemesi kullanılarak belirlenebilir. Bu tür çalışmaların sonuçlarının mevcut bulgularla karşılaştırılması literatüre katkı sağlayacak potansiyel bir araştırma konusudur.

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Tasarım / *Design*	Yöntemi, ölçeği ve deseni tasarlamak / *Designing method, scale and pattern*	Rahmi BAKİ
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Literatür Taraması / *Literature Review*	Çalışma için gerekli literatürü taramak / *Review the literature required for the study*	Rahmi BAKİ

Appendix 1. DM

	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
A_1	54.2	62.4	58.1	69.6	68.9	70.8	56.4	61.1	55.4	69.8	67.4	75.6	77.7	69.3	70.1	74.8	51.2	64	63.4	69.9
A_2	83.4	74.1	79.7	79.6	79	89.1	64.8	77	79.5	87.4	86.2	90.9	86.9	81.8	80	87.8	76.1	75.5	83.3	80.4
A_3	64	58.1	55.7	70	51.7	77.2	63.3	57.8	63.4	72.3	68.3	77.8	79.7	68.8	73.5	76.4	79.7	68.8	63.3	76.8
A_4	41.4	41.2	50.5	48.1	40	57.3	42.1	37.6	46.8	46.7	54.8	71.9	55.3	48.5	48.3	55.4	24.9	32.8	39.5	53.8
A_5	47	50.6	56.1	53	30.9	62.3	47.4	49.6	58.4	57.4	67.9	77	53.6	39.9	46.8	61.2	32.3	39.3	47.8	64.4
A_6	49.4	48.8	42.9	69.1	39.9	69.2	57.6	62.7	45	65.4	60	70.6	69.6	48.1	61.2	57.5	42.1	52.9	51.7	59.4
A_7	79.7	66.7	77.1	74.1	70.6	86.2	65.4	77.3	81.2	87.4	84.8	88.9	83	76.1	75.2	86	65.4	67.5	78.4	75.8
A_8	82.7	74.7	77.1	80.6	78.1	88.1	69.5	77.3	72.1	84.3	84.5	89.1	84.9	77.1	77.2	88.8	72.9	75.4	80.1	78.2
A_9	65.4	63.1	66.4	73.3	65.3	78.2	64	62.1	63.2	73.7	72.4	78.1	73.7	68.2	73.6	73.4	66	64	72.4	76.3
A_{10}	83.8	76.4	82.9	82.4	78.8	90.1	65	77.8	76.8	89.9	88.8	92	87.3	83.3	85.2	88.3	76.4	75.4	83.6	85.5
A_{11}	82.9	78.1	81.2	81.4	74.7	90.3	68.6	79.1	84.1	86.9	88.7	89.7	86.9	80.3	81.6	89.8	73.9	76.1	78.6	83
A_{12}	74.2	65	64.7	77.5	59.9	76.4	69.6	72.2	48.6	74.1	66.5	80.4	83.6	77.6	77	78.8	57.4	64.3	68.9	75.6
A_{13}	61.8	54.9	55	77	47.8	75.1	65.6	55.8	55.3	79	64.9	77.6	76.7	65.8	75.7	74.7	53.6	55.3	64.1	76
A_{14}	62	66.3	62.5	66	53.6	84.2	45.2	51.4	58.1	65.4	84.3	79.9	72.3	58.7	59.2	60.7	46.6	49.2	53	73
A_{15}	64.1	61.4	67.7	75	61.6	74.8	62.5	60.1	62.5	80.7	75.8	80.4	78.2	70.8	77	74.8	57.3	63.2	69	75.2
A_{16}	50.4	39.4	34.1	36.2	23.9	46.9	46.6	37.7	26.2	56.8	54.6	73.6	68	50.5	55.5	59.3	22.3	23.4	34.6	52.2
A_{17}	46.6	62.3	59.7	56.5	43.6	64.6	42	45.5	56.8	66.1	62.9	75.3	68.9	62.5	55.2	68.8	44.4	56.9	51.3	61.7
A_{18}	51.5	62.3	59.6	56.3	53.3	64.8	54.2	55.4	49.4	60.8	67.1	76.6	70.3	56.6	59.2	68.1	50.7	66.6	57.2	63.3
A_{19}	59.4	52.9	54.9	67.1	40.7	63	53.9	52.4	52.8	62.5	64.9	73.1	80.2	64.8	68.7	54.7	48.7	57.4	55.5	72.1
A_{20}	39	45.3	53.4	48	46.3	54.6	42.2	46.4	52.6	49.5	60.5	74.5	57.4	46.3	49.9	59.1	32.7	40.1	44.8	64.2
A_{21}	68.8	59.9	69.9	67.3	50.5	72.7	49.6	66.6	59.8	75.3	56.8	81.4	79.9	62.9	61.7	74.8	44.6	60.5	62.7	72.9
A_{22}	63.1	57.4	66.8	77	57.4	78.7	65.5	60.8	59.6	79.6	75.9	80.8	79	71.4	77	74.9	59.6	64.5	68.3	79
A_{23}	53.8	59.5	65.4	60.2	49.7	67.8	55.7	59.4	58.5	66.3	67.8	79.4	71.4	55.9	59.7	69.8	50.4	59.8	54.8	64.9
A_{24}	45	55.5	44.7	53.1	33.2	44.1	24.2	35.4	26.3	48.7	54.9	53.3	54.4	31.2	32.4	53.8	29.9	27.2	31	36.6
A_{25}	46	64	52.8	51.9	52.6	72	42.2	46.3	54.1	63.4	61.5	77	55.1	54.7	47.3	67.5	39	44.5	48.5	60.2

	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
A_{26}	27.2	39.8	30.9	40.5	23	38.9	41.8	44.1	48.3	51.9	53.3	76.1	51.8	24.5	38.6	50.6	22	37.8	35	52.2
A_{27}	33.5	39.9	41.8	41.5	32.9	49	43.2	49.5	48.8	54.8	56.6	72.8	56.3	31.3	49.3	51.3	26	42.8	42.8	60.2
A_{28}	59.1	67.2	74.6	74.1	66.3	70.4	45.6	52.9	49.7	71.6	78.2	77.7	64.8	60.7	56.1	78.5	43.9	59	60.2	74.5
A_{29}	83.7	74.8	79.8	79.3	78.4	89	65.1	81.3	75.5	87.9	87.2	90.6	86.1	83.8	81	89.5	70.2	72.5	80.8	83.4
A_{30}	83.6	79.7	82.5	84.7	80.8	90.2	73.1	81	79.5	91.4	88.3	89.9	85	82.8	84.6	88.5	76	77.8	81.8	87.2
A_{31}	83.1	72.7	82.2	84	75.4	89.3	73.3	77.5	78.7	86.6	87	89.6	86.9	80.5	76.5	86.8	68.4	66.7	76.5	75.5
A_{32}	46.5	62.1	48.7	55.9	35.8	52.6	21.7	36.5	26.6	54.3	60.3	62.6	60	35.1	40.6	57.1	29.8	30.1	33.5	45.5

Appendix 2. Normalized DM by CRITIC technique

	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
A_{1}	0.477	0.571	0.523	0.689	0.794	0.621	0.672	0.56	0.56	0.517	0.397	0.576	0.73	0.755	0.714	0.617	0.506	0.746	0.616	0.658
A_{2}	0.993	0.861	0.938	0.895	0.969	0.977	0.835	0.906	0.906	0.911	0.927	0.972	0.989	0.966	0.902	0.949	0.938	0.958	0.994	0.866
A_{3}	0.65	0.464	0.477	0.697	0.497	0.745	0.806	0.488	0.488	0.573	0.423	0.633	0.786	0.747	0.778	0.658	1	0.835	0.614	0.794
A_{4}	0.251	0.045	0.377	0.245	0.294	0.358	0.395	0.048	0.048	0	0.042	0.481	0.099	0.405	0.301	0.122	0.05	0.173	0.162	0.34
A_{5}	0.35	0.278	0.485	0.346	0.137	0.455	0.498	0.309	0.309	0.239	0.411	0.612	0.051	0.26	0.273	0.27	0.179	0.292	0.319	0.549
A_{6}	0.392	0.233	0.231	0.678	0.292	0.589	0.696	0.595	0.595	0.418	0.189	0.447	0.501	0.398	0.545	0.176	0.348	0.542	0.394	0.451
A_{7}	0.928	0.677	0.888	0.781	0.824	0.92	0.847	0.913	0.913	0.911	0.887	0.92	0.879	0.87	0.811	0.903	0.752	0.811	0.901	0.775
A_{8}	0.981	0.876	0.888	0.915	0.953	0.957	0.926	0.913	0.913	0.841	0.879	0.925	0.932	0.887	0.848	0.974	0.882	0.956	0.933	0.822
A_{9}	0.675	0.588	0.683	0.765	0.732	0.765	0.82	0.582	0.582	0.604	0.538	0.641	0.617	0.737	0.78	0.582	0.763	0.746	0.787	0.785
A_{10}	1	0.918	1	0.953	0.965	0.996	0.839	0.924	0.924	0.966	1	1	1	0.992	1	0.962	0.943	0.956	1	0.966
A_{11}	0.984	0.96	0.967	0.932	0.894	1	0.909	0.952	0.952	0.899	0.997	0.941	0.989	0.941	0.932	1	0.899	0.969	0.905	0.917
A_{12}	0.83	0.635	0.65	0.852	0.638	0.73	0.928	0.802	0.802	0.613	0.372	0.7	0.896	0.895	0.845	0.719	0.614	0.752	0.721	0.771
A_{13}	0.611	0.385	0.463	0.841	0.429	0.704	0.851	0.444	0.444	0.723	0.327	0.628	0.701	0.696	0.82	0.615	0.548	0.586	0.629	0.779
A_{14}	0.615	0.667	0.608	0.614	0.529	0.881	0.455	0.349	0.349	0.418	0.873	0.687	0.577	0.577	0.508	0.258	0.426	0.474	0.418	0.719
A_{15}	0.652	0.546	0.708	0.8	0.668	0.698	0.791	0.538	0.538	0.761	0.634	0.7	0.744	0.781	0.845	0.617	0.612	0.732	0.722	0.763
A_{16}	0.41	0	0.062	0	0.016	0.156	0.483	0.05	0.05	0.226	0.037	0.525	0.456	0.438	0.438	0.222	0.005	0.000	0.068	0.308
A_{17}	0.343	0.568	0.554	0.419	0.356	0.5	0.393	0.22	0.22	0.434	0.27	0.568	0.482	0.641	0.432	0.464	0.388	0.616	0.386	0.496

	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
A_{18}	0.429	0.568	0.552	0.414	0.524	0.504	0.63	0.436	0.436	0.315	0.389	0.602	0.521	0.541	0.508	0.446	0.497	0.794	0.498	0.528
A_{19}	0.569	0.335	0.462	0.637	0.306	0.469	0.624	0.37	0.37	0.353	0.327	0.512	0.8	0.68	0.688	0.105	0.463	0.625	0.466	0.702
A_{20}	0.208	0.146	0.433	0.243	0.403	0.305	0.397	0.24	0.24	0.063	0.203	0.548	0.158	0.368	0.331	0.217	0.185	0.307	0.262	0.545
A_{21}	0.735	0.509	0.75	0.641	0.476	0.658	0.541	0.68	0.68	0.64	0.099	0.726	0.792	0.648	0.555	0.617	0.392	0.682	0.603	0.717
A_{22}	0.634	0.447	0.69	0.841	0.595	0.774	0.849	0.553	0.553	0.736	0.637	0.711	0.766	0.791	0.845	0.62	0.652	0.756	0.709	0.838
A_{23}	0.47	0.499	0.663	0.495	0.462	0.562	0.659	0.523	0.523	0.438	0.408	0.674	0.552	0.53	0.517	0.49	0.492	0.669	0.452	0.559
A_{24}	0.314	0.4	0.265	0.348	0.176	0.101	0.048	0	0	0.045	0.045	0	0.073	0.113	0	0.082	0.137	0.07	0	0
A_{25}	0.332	0.61	0.421	0.324	0.512	0.644	0.397	0.237	0.237	0.374	0.231	0.612	0.093	0.509	0.282	0.431	0.295	0.388	0.333	0.466
A_{26}	0	0.01	0	0.089	0	0	0.39	0.19	0.19	0.116	0	0.589	0	0	0.117	0	0	0.265	0.076	0.308
A_{27}	0.111	0.012	0.21	0.109	0.171	0.196	0.417	0.307	0.307	0.181	0.093	0.504	0.127	0.115	0.32	0.018	0.069	0.357	0.224	0.466
A_{28}	0.564	0.69	0.84	0.781	0.749	0.613	0.463	0.381	0.381	0.557	0.701	0.63	0.366	0.61	0.449	0.712	0.38	0.654	0.555	0.749
A_{29}	0.998	0.878	0.94	0.889	0.958	0.975	0.841	1	1	0.922	0.955	0.964	0.966	1	0.92	0.992	0.835	0.903	0.947	0.925
A_{30}	0.996	1	0.992	1	1	0.998	0.996	0.993	0.993	1	0.986	0.946	0.935	0.983	0.989	0.967	0.936	1	0.966	1
A_{31}	0.988	0.826	0.987	0.986	0.907	0.981	1	0.917	0.917	0.893	0.949	0.938	0.989	0.944	0.835	0.923	0.804	0.796	0.865	0.769
A_{32}	0.341	0.563	0.342	0.406	0.221	0.267	0	0.024	0.024	0.17	0.197	0.24	0.231	0.179	0.155	0.166	0.135	0.123	0.048	0.176

Appendix 3. Correlation Matrix

	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
C_{11}	1	0.850	0.893	0.897	0.876	0.914	0.793	0.897	0.897	0.929	0.861	0.798	0.922	0.922	0.882	0.916	0.896	0.822	0.922	0.827
C_{12}	0.85	1	0.892	0.823	0.892	0.854	0.549	0.762	0.762	0.819	0.857	0.667	0.728	0.793	0.672	0.863	0.82	0.786	0.808	0.686
C_{13}	0.893	0.892	1	0.854	0.927	0.896	0.683	0.843	0.843	0.868	0.894	0.808	0.778	0.864	0.769	0.909	0.835	0.843	0.902	0.828
C_{14}	0.897	0.823	0.854	1	0.868	0.904	0.793	0.852	0.852	0.907	0.817	0.676	0.869	0.877	0.874	0.854	0.893	0.865	0.911	0.84
C_{15}	0.876	0.892	0.927	0.868	1	0.908	0.74	0.869	0.869	0.879	0.886	0.798	0.796	0.894	0.822	0.926	0.878	0.877	0.93	0.829
C_{16}	0.914	0.854	0.896	0.904	0.908	1	0.811	0.878	0.878	0.918	0.892	0.836	0.848	0.918	0.874	0.893	0.909	0.872	0.935	0.89
C_{21}	0.793	0.549	0.683	0.793	0.74	0.811	1	0.876	0.876	0.85	0.697	0.82	0.847	0.853	0.936	0.792	0.844	0.851	0.892	0.869
C_{22}	0.897	0.762	0.843	0.852	0.869	0.878	0.876	1	1	0.918	0.812	0.871	0.87	0.851	0.877	0.885	0.872	0.903	0.948	0.855
C_{23}	0.897	0.762	0.843	0.852	0.869	0.878	0.876	1	1	0.918	0.812	0.871	0.87	0.851	0.877	0.885	0.872	0.903	0.948	0.855
C_{24}	0.929	0.819	0.868	0.907	0.879	0.918	0.85	0.918	0.918	1	0.854	0.853	0.9	0.913	0.915	0.94	0.905	0.887	0.958	0.882
C_{35}	0.861	0.857	0.894	0.817	0.886	0.892	0.697	0.812	0.812	0.854	1	0.819	0.747	0.806	0.771	0.839	0.836	0.787	0.864	0.814
C_{36}	0.798	0.667	0.808	0.676	0.798	0.836	0.82	0.871	0.871	0.853	0.819	1	0.753	0.814	0.808	0.844	0.768	0.808	0.876	0.875
C_{31}	0.922	0.728	0.778	0.869	0.796	0.848	0.847	0.87	0.87	0.9	0.747	0.753	1	0.931	0.944	0.838	0.889	0.867	0.896	0.834
C_{32}	0.922	0.793	0.864	0.877	0.894	0.918	0.853	0.851	0.851	0.913	0.806	0.814	0.931	1	0.943	0.913	0.905	0.881	0.937	0.889
C_{33}	0.882	0.672	0.769	0.874	0.822	0.874	0.936	0.877	0.877	0.915	0.771	0.808	0.944	0.943	1	0.847	0.907	0.888	0.939	0.919
C_{34}	0.916	0.863	0.909	0.854	0.926	0.893	0.792	0.885	0.885	0.94	0.839	0.844	0.838	0.913	0.847	1	0.892	0.869	0.935	0.833
C_{41}	0.896	0.82	0.835	0.893	0.878	0.909	0.844	0.872	0.872	0.905	0.836	0.768	0.889	0.905	0.907	0.892	1	0.931	0.94	0.864
C_{42}	0.822	0.786	0.843	0.865	0.877	0.872	0.851	0.903	0.903	0.887	0.787	0.808	0.867	0.881	0.888	0.869	0.931	1	0.947	0.895
C_{43}	0.922	0.808	0.902	0.911	0.93	0.935	0.892	0.948	0.948	0.958	0.864	0.876	0.896	0.937	0.939	0.935	0.940	0.947	1	0.931
C_{44}	0.827	0.686	0.828	0.84	0.829	0.89	0.869	0.855	0.855	0.882	0.814	0.875	0.834	0.889	0.919	0.833	0.864	0.895	0.931	1

Appendix 4. C_j and w_j Values of Evaluation Criteria

	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
$\sum_{k=1}^{n}(1-\rho_{jk})$	2.29	4.12	2.87	2.77	2.54	2.17	3.63	2.36	2.36	1.99	3.33	3.64	2.87	2.24	2.53	2.33	2.34	2.52	1.58	2.79
σ_j	0.29	0.29	0.28	0.29	0.30	0.29	0.26	0.31	0.31	0.30	0.34	0.22	0.33	0.28	0.28	0.33	0.31	0.29	0.31	0.24
C_j	0.67	1.18	0.80	0.80	0.76	0.63	0.94	0.74	0.74	0.60	1.13	0.80	0.96	0.64	0.71	0.76	0.73	0.72	0.49	0.67
w_j	0.04	0.08	0.05	0.05	0.05	0.04	0.06	0.05	0.05	0.04	0.07	0.05	0.06	0.04	0.05	0.05	0.05	0.05	0.03	0.04

Appendix 5. Normalized DM by CODAS technique

	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
A_1	0.647	0.783	0.701	0.822	0.853	0.784	0.769	0.752	0.659	0.764	0.759	0.822	0.890	0.827	0.823	0.833	0.642	0.823	0.758	0.802
A_2	0.995	0.93	0.961	0.94	0.978	0.987	0.884	0.947	0.945	0.956	0.971	0.988	0.995	0.976	0.939	0.978	0.955	0.97	0.996	0.922
A_3	0.764	0.729	0.672	0.826	0.64	0.855	0.864	0.711	0.754	0.791	0.769	0.846	0.913	0.821	0.863	0.851	1	0.884	0.757	0.881
A_4	0.494	0.517	0.609	0.568	0.495	0.635	0.574	0.462	0.556	0.511	0.617	0.782	0.633	0.579	0.567	0.617	0.312	0.422	0.472	0.617
A_5	0.561	0.635	0.677	0.626	0.382	0.69	0.647	0.61	0.694	0.628	0.765	0.837	0.614	0.476	0.549	0.682	0.405	0.505	0.572	0.739
A_6	0.589	0.612	0.517	0.816	0.494	0.766	0.786	0.771	0.535	0.716	0.676	0.767	0.797	0.574	0.718	0.64	0.528	0.680	0.618	0.681
A_7	0.951	0.837	0.93	0.875	0.874	0.955	0.892	0.951	0.966	0.956	0.955	0.966	0.951	0.908	0.883	0.958	0.821	0.868	0.938	0.869
A_8	0.987	0.937	0.93	0.952	0.967	0.976	0.948	0.951	0.857	0.922	0.952	0.968	0.973	0.92	0.906	0.989	0.915	0.969	0.958	0.897
A_9	0.78	0.792	0.801	0.865	0.808	0.866	0.873	0.764	0.751	0.806	0.815	0.849	0.844	0.814	0.864	0.817	0.828	0.823	0.866	0.875
A_{10}	1	0.959	1	0.973	0.975	0.998	0.887	0.957	0.913	0.984	1	1	1	0.994	1	0.983	0.959	0.969	1	0.981
A_{11}	0.989	0.98	0.979	0.961	0.925	1	0.936	0.973	1	0.951	0.999	0.975	0.995	0.958	0.958	1	0.927	0.978	0.94	0.952
A_{12}	0.885	0.816	0.78	0.915	0.741	0.846	0.95	0.888	0.578	0.811	0.749	0.874	0.958	0.926	0.904	0.878	0.72	0.826	0.824	0.867
A_{13}	0.737	0.689	0.663	0.909	0.592	0.832	0.895	0.686	0.658	0.864	0.731	0.843	0.879	0.785	0.888	0.832	0.673	0.711	0.767	0.872
A_{14}	0.74	0.832	0.754	0.779	0.663	0.932	0.617	0.632	0.691	0.716	0.949	0.868	0.828	0.7	0.695	0.676	0.585	0.632	0.634	0.837
A_{15}	0.765	0.77	0.817	0.885	0.762	0.828	0.853	0.739	0.743	0.883	0.854	0.874	0.896	0.845	0.904	0.833	0.719	0.812	0.825	0.862
A_{16}	0.601	0.494	0.411	0.427	0.296	0.519	0.636	0.464	0.312	0.621	0.615	0.8	0.779	0.603	0.651	0.66	0.28	0.301	0.414	0.599
A_{17}	0.556	0.782	0.72	0.667	0.54	0.715	0.573	0.56	0.675	0.723	0.708	0.818	0.789	0.746	0.648	0.766	0.557	0.731	0.614	0.708

	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
A_{18}	0.615	0.782	0.719	0.665	0.66	0.718	0.739	0.681	0.587	0.665	0.756	0.833	0.805	0.675	0.695	0.758	0.636	0.856	0.684	0.726
A_{19}	0.709	0.664	0.662	0.792	0.504	0.698	0.735	0.645	0.628	0.684	0.731	0.795	0.919	0.773	0.806	0.609	0.611	0.738	0.664	0.827
A_{20}	0.465	0.568	0.644	0.567	0.573	0.605	0.576	0.571	0.625	0.542	0.681	0.81	0.658	0.553	0.586	0.658	0.41	0.515	0.536	0.736
A_{21}	0.821	0.752	0.843	0.795	0.625	0.805	0.677	0.819	0.711	0.824	0.64	0.885	0.915	0.751	0.724	0.833	0.56	0.778	0.75	0.836
A_{22}	0.753	0.72	0.806	0.909	0.71	0.872	0.894	0.748	0.709	0.871	0.855	0.878	0.905	0.852	0.904	0.834	0.748	0.829	0.817	0.906
A_{23}	0.642	0.747	0.789	0.711	0.615	0.751	0.76	0.731	0.696	0.725	0.764	0.863	0.818	0.667	0.701	0.777	0.632	0.769	0.656	0.744
A_{24}	0.537	0.696	0.539	0.627	0.411	0.488	0.33	0.435	0.313	0.533	0.618	0.579	0.623	0.372	0.38	0.599	0.375	0.35	0.371	0.42
A_{25}	0.549	0.803	0.637	0.613	0.651	0.797	0.576	0.569	0.643	0.694	0.693	0.837	0.631	0.653	0.555	0.752	0.489	0.572	0.58	0.69
A_{26}	0.325	0.499	0.373	0.478	0.285	0.431	0.57	0.542	0.574	0.568	0.6	0.827	0.593	0.292	0.453	0.563	0.276	0.486	0.419	0.599
A_{27}	0.4	0.501	0.504	0.49	0.407	0.543	0.589	0.609	0.58	0.6	0.637	0.791	0.645	0.374	0.579	0.571	0.326	0.55	0.512	0.69
A_{28}	0.705	0.843	0.9	0.875	0.821	0.78	0.622	0.651	0.591	0.783	0.881	0.845	0.742	0.724	0.658	0.874	0.551	0.758	0.72	0.854
A_{29}	0.999	0.939	0.963	0.936	0.97	0.986	0.888	1	0.898	0.962	0.982	0.985	0.986	1	0.951	0.997	0.881	0.932	0.967	0.956
A_{30}	0.998	1	0.995	1	1	0.999	0.997	0.996	0.945	1	0.994	0.977	0.974	0.988	0.993	0.986	0.954	1	0.978	1
A_{31}	0.992	0.912	0.992	0.992	0.933	0.989	1	0.953	0.936	0.947	0.98	0.974	0.995	0.961	0.898	0.967	0.858	0.857	0.915	0.866
A_{32}	0.555	0.779	0.587	0.66	0.443	0.583	0.296	0.449	0.316	0.594	0.679	0.68	0.687	0.419	0.477	0.636	0.374	0.387	0.401	0.522

Appendix 6. Weighted DM

	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
A_1	0.028	0.06	0.036	0.043	0.042	0.032	0.047	0.036	0.031	0.03	0.056	0.042	0.055	0.034	0.038	0.041	0.03	0.038	0.024	0.035
A_2	0.043	0.071	0.05	0.049	0.048	0.04	0.054	0.045	0.045	0.037	0.071	0.051	0.062	0.04	0.043	0.048	0.045	0.045	0.031	0.04
A_3	0.033	0.056	0.035	0.043	0.032	0.035	0.052	0.034	0.036	0.031	0.056	0.044	0.056	0.034	0.04	0.042	0.047	0.041	0.024	0.038
A_4	0.021	0.039	0.032	0.029	0.024	0.026	0.035	0.022	0.027	0.020	0.045	0.040	0.039	0.024	0.026	0.03	0.015	0.02	0.015	0.027
A_5	0.024	0.048	0.035	0.032	0.019	0.028	0.039	0.029	0.033	0.025	0.056	0.043	0.038	0.02	0.025	0.034	0.019	0.024	0.018	0.032
A_6	0.025	0.047	0.027	0.042	0.024	0.031	0.048	0.037	0.026	0.028	0.049	0.040	0.049	0.024	0.033	0.032	0.025	0.032	0.019	0.029
A_7	0.041	0.064	0.048	0.045	0.043	0.039	0.054	0.045	0.046	0.037	0.07	0.05	0.059	0.038	0.041	0.047	0.039	0.04	0.029	0.037
A_8	0.043	0.071	0.048	0.049	0.048	0.04	0.057	0.045	0.041	0.036	0.07	0.05	0.06	0.038	0.042	0.049	0.043	0.045	0.03	0.039
A_9	0.034	0.06	0.042	0.045	0.04	0.035	0.053	0.037	0.036	0.032	0.06	0.044	0.052	0.034	0.04	0.04	0.039	0.038	0.027	0.038

	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
A_{10}	0.043	0.073	0.052	0.05	0.048	0.041	0.054	0.046	0.044	0.038	0.073	0.052	0.062	0.041	0.046	0.048	0.045	0.045	0.031	0.042
A_{11}	0.043	0.075	0.051	0.05	0.046	0.041	0.057	0.047	0.048	0.037	0.073	0.05	0.062	0.04	0.044	0.049	0.044	0.046	0.03	0.041
A_{12}	0.038	0.062	0.041	0.047	0.037	0.034	0.058	0.042	0.028	0.032	0.055	0.045	0.059	0.038	0.042	0.043	0.034	0.039	0.026	0.037
A_{13}	0.032	0.053	0.034	0.047	0.029	0.034	0.054	0.033	0.031	0.034	0.053	0.044	0.054	0.032	0.041	0.041	0.032	0.033	0.024	0.038
A_{14}	0.032	0.063	0.039	0.04	0.033	0.038	0.037	0.03	0.033	0.028	0.069	0.045	0.051	0.029	0.032	0.033	0.028	0.029	0.02	0.036
A_{15}	0.033	0.059	0.042	0.046	0.038	0.034	0.052	0.035	0.036	0.035	0.062	0.045	0.055	0.035	0.042	0.041	0.034	0.038	0.026	0.037
A_{16}	0.026	0.038	0.021	0.022	0.015	0.021	0.039	0.022	0.015	0.024	0.045	0.041	0.048	0.025	0.03	0.033	0.013	0.014	0.013	0.026
A_{17}	0.024	0.06	0.037	0.035	0.027	0.029	0.035	0.027	0.032	0.028	0.052	0.042	0.049	0.031	0.03	0.038	0.026	0.034	0.019	0.030
A_{18}	0.027	0.06	0.037	0.034	0.033	0.029	0.045	0.033	0.028	0.026	0.055	0.043	0.05	0.028	0.032	0.037	0.03	0.04	0.022	0.031
A_{19}	0.031	0.051	0.034	0.041	0.025	0.028	0.045	0.031	0.03	0.027	0.053	0.041	0.057	0.032	0.037	0.03	0.029	0.034	0.021	0.036
A_{20}	0.02	0.043	0.033	0.029	0.028	0.025	0.035	0.027	0.03	0.021	0.05	0.042	0.041	0.023	0.027	0.032	0.019	0.024	0.017	0.032
A_{21}	0.035	0.057	0.044	0.041	0.031	0.033	0.041	0.039	0.034	0.032	0.047	0.046	0.057	0.031	0.033	0.041	0.026	0.036	0.024	0.036
A_{22}	0.032	0.055	0.042	0.047	0.035	0.035	0.054	0.036	0.034	0.034	0.063	0.045	0.056	0.035	0.042	0.041	0.035	0.039	0.026	0.039
A_{23}	0.028	0.057	0.041	0.037	0.03	0.031	0.046	0.035	0.033	0.028	0.056	0.045	0.051	0.028	0.032	0.038	0.03	0.036	0.021	0.032
A_{24}	0.023	0.053	0.028	0.033	0.02	0.02	0.02	0.021	0.015	0.021	0.045	0.03	0.039	0.015	0.018	0.03	0.018	0.016	0.012	0.018
A_{25}	0.024	0.061	0.033	0.032	0.032	0.032	0.035	0.027	0.031	0.027	0.051	0.043	0.039	0.027	0.026	0.037	0.023	0.027	0.018	0.03
A_{26}	0.014	0.038	0.019	0.025	0.014	0.018	0.035	0.026	0.027	0.022	0.044	0.043	0.037	0.012	0.021	0.028	0.013	0.023	0.013	0.026
A_{27}	0.017	0.038	0.026	0.025	0.02	0.022	0.036	0.029	0.028	0.023	0.047	0.041	0.04	0.015	0.027	0.028	0.015	0.026	0.016	0.03
A_{28}	0.03	0.064	0.047	0.045	0.04	0.032	0.038	0.031	0.028	0.031	0.064	0.044	0.046	0.03	0.03	0.043	0.026	0.035	0.023	0.037
A_{29}	0.043	0.072	0.05	0.049	0.048	0.04	0.054	0.048	0.043	0.038	0.072	0.051	0.061	0.041	0.044	0.049	0.041	0.043	0.03	0.041
A_{30}	0.043	0.076	0.052	0.052	0.049	0.041	0.06	0.048	0.045	0.039	0.073	0.05	0.06	0.041	0.046	0.049	0.045	0.047	0.031	0.043
A_{31}	0.043	0.07	0.051	0.051	0.046	0.04	0.061	0.046	0.045	0.037	0.072	0.05	0.062	0.04	0.041	0.048	0.04	0.04	0.029	0.037
A_{32}	0.024	0.059	0.03	0.034	0.022	0.024	0.018	0.021	0.015	0.023	0.05	0.035	0.043	0.017	0.022	0.031	0.018	0.018	0.013	0.022

Appendix 7 E_i and T_i Values of Alternatives

A_j	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}
E_i	0.083	0.122	0.091	0.036	0.049	0.060	0.112	0.119	0.093	0.125	0.125	0.097	0.082	0.076	0.092	0.036
T_i	0.355	0.536	0.385	0.133	0.198	0.244	0.490	0.521	0.401	0.552	0.547	0.414	0.350	0.324	0.401	0.108
A_j	A_{17}	A_{18}	A_{19}	A_{20}	A_{21}	A_{22}	A_{23}	A_{24}	A_{25}	A_{26}	A_{27}	A_{28}	A_{29}	A_{30}	A_{31}	A_{32}
E_i	0.062	0.070	0.069	0.044	0.079	0.093	0.072	0.024	0.056	0.028	0.035	0.080	0.122	0.130	0.120	0.034
T_i	0.262	0.296	0.289	0.176	0.341	0.402	0.310	0.070	0.231	0.074	0.127	0.342	0.535	0.566	0.525	0.117

Appendix 8. Evaluation Scores of Alternatives

A_j	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}
H_i	0.28	1.761	0.548	-0.514	-0.743	-0.45	0.433	1.517	0.565	1.736	1.755	0.729	0.175	-0.052	0.516	-1.478
A_j	A_{17}	A_{18}	A_{19}	A_{20}	A_{21}	A_{22}	A_{23}	A_{24}	A_{25}	A_{26}	A_{27}	A_{28}	A_{29}	A_{30}	A_{31}	A_{32}
H_i	-0.63	-0.329	-0.358	-1.212	-0.018	0.429	-0.177	-1.861	-0.754	-1.730	-1.449	0	0.988	1.16	0.97	-1.837