Int. J. Urban Manage Energy Sustainability, 2(3): 59-66 Summer 2021

DOI: 10.22034/JUMES.2021.249029

Case Study

Sustainable Smart Cities: Based on Fuzzy DEMATEL Approach

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Received 4 Apr 2021 revised 12 Jul 2021 accepted 25 Aug 2021 available online 28 Sep 2021

ABSTRACT: New urban planning paradigms have provided a new framework based on sustainable cities for urbanization. Nowadays, a smart solution is submitted by day and these solutions make cities radically change the way they are managed today. According to this view, various dimensions can be offered for a sustainable smart city. To determine the smart sustainable city concept, need to define the dimensions of a specific city are smart and sustainable. So, this study aims to analyze the causal relationships of sustainable smart city dimensions. therefore, a fuzzy DEMATEL solution is developed and presented. The population is 42 urban developers who are chosen reasonably. A pairwise matrices questionnaire was made to compare and match each couple of criteria. A group of experts evaluated the correlation between criteria. Then, the linguistic variables were put into triangular fuzzy numbers and then their opinion about the criteria was collected. After that, the crisp total direct relation matrix, the fuzzy, and the normalized matrix of direct relation were calculated. Findings showed that Policy factors affect all six other factors and are influenced by all the other factors except Environmental factors. Governance factors influence all six other factors and are affected by Policy and Business factors. Economic factors affect all the other factors except Governance factors. Environmental factors are affected by four other factors (Policy, Economic, Governance, Inhabitant). The Inhabitant factors have the most interaction (influence/influence) with other criteria and since (D_i-R_i) is negative for Inhabitant factors, so this criterion is a net effect. The Governance factors after Inhabitant factors have the most interaction (impact/influence) with other criteria and since (D_i-R_i) is positive for Governance factors, so this criterion is a net cause. Given that the value (D_i-R_i) is positive, the criteria of Policy factors, Economic factors, and Environmental factors are also net causes. This approach can develop a robust management approach that can be used in different smart city environments.

Keywords: Fuzzy System, DEMATEL, Smart Cities, Sustainable Smart Cities, Analyzing Causal Relationships.

RUNNING TITLE: Sustainable Smart Cities

INTRODUCTION

When we speak of Smart City, you can follow it up to Smart Growth Movement of the 1990s (Batty, 2013) Jin and et al, (2014), suggested it comes back earlier, i.e., to "cybernetic planned cities" of the 60s, to recommendations for networked city or computable one in planning urban development from 80s ahead.

It was the business sector that made the concept of Smart City advanced. It is key for many companies engaged in infrastructure and ICT to be interested.

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From the point of business, if we can reload ICT solutions into a framework of smart city, we will have this potential to get going some kind of wholesale concept and also to guide it to public sectors of city authorities.

Modern societies with their increased population which is accompanied by industrial development shall result in enhanced economies. Flourishing economies, fast urbanization, and enhancing the living standards of society have considerably accelerated the rate of production of waste in developing countries (Minghua et al, 2009).

Citizens in smart cities are provided with information about multiple urban services and are allowed to follow up on the effect of their consumption on the total city sustainability. The smart city assumes that if your access to information about resource consumption shall be improved, it will result in better exploitation of those resources for residents and increased city sustainability (Khansari et al, 2014).

Urban areas are where more than half of the population of the world are living and also where more energy, land, and other resources are used. The continuing focus of the population on urban places suggests that these matters are increasingly important as they address the issues of sustainable development. In other notation, sustainable development of urban areas has become a rudiment for sustainable development (Economic Times, 2020).

Hence, to analyze a functional administration of a smart city, we hereby present a Fuzzy DEMATEL as precedence for assessing smart city technology. In the following section, the literature will be reviewed and in further section, the methodology of collecting data and the DEMATEL technique. In the two last parts, we will analyze the data and discuss the results and conclude.

Sustainable Smart City Dimensions: A Brief Review

The importance of environmental protection, concern about urbanization, and also technological development established a new framework to construct and design cities. If a city is not sustainable in the first place, it cannot be called smart (Yigitcanlar et al., 2019).

By investing in ICTs to promote sustainable development and life quality, governments and private sectors are providing infrastructures for smart cities to inform citizens about the demanded environment. Citizens in smart cities are provided needed infrastructures to be more intelligent in making decisions. Smart cities have so many challenges regarding social, cultural, economic, and ecological sustainability. They should provide information for residents about various services and let them follow up on their effect on resource consumption. The smart city assumes that if your access to information about resource consumption shall be improved, it will result in better exploitation of those resources for residents and increased city sustainability (Khansari et al, 2014).

Researchers and urban developers have presented different rankings for smart cities which are discussed at national and international levels and help urban policies to be evaluated and developed (Meijering, Kern, and Tobi 2014). For example, the Triple Helix model of smart cities is one of the most accepted models in this matter which is identified by Monfaredzadeh and Berardi (2015) for producing and classifying smart city indices. Lombardi et al. (2012), prepared a triple helix model (universities, industry, and government) by adding a fourth model (civil society) to enhance knowledge-based innovation in SSCC characterization. A six-dimensional framework (cities' mobility, environment, people, living, governance, and economy), to classify European cities towards smart city development was presented by Giffinger et al. European Smart Cities Ranking which is one of the most accepted rankings all over the world (Giffinger, Kramar, and Hindl 2008). The former matches up the mutual and multiple relationships between those three means for creating and capitalizing knowledge, i.e., government, industry, and university, and makes a set of benchmarks to assess the smartness of a city (Bhattacharyaa and et al, 2018). Figure 1 illustrates the Initiative Framework for Smart

Cities.

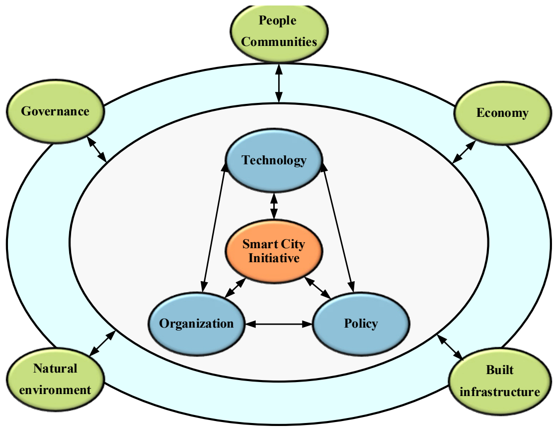


Fig 1: Initiative Framework of Smart City (Chourabi et al. 2012, 7)

Social Sustainability

Security, quality of life, stability, and business opportunities are those strong factors that attract businesses, investments, and people and the social totality could offer them. Smart people, who are engaged in sustainable living, could develop smart cities. You can define sustainability in this matter to reduce using resources which are not renewable, preserving environment, powerful and manifold economy, independent societies as well as diversity and vitality of the economy, welfare and satisfying initial needs of human. As per Bouzguenda, Alalouch & Fava, (2019), ICT could enhance citizens' participation, develop social and environmental, and human assets in smart cities which makes them social-oriented. It is essential policies that are extracted from society perspectives, user's satisfaction and focus on around design to make sustainability for smart cities (Macke, Rubim Sarate & de Atayde Moschen, 2019).

Economic Sustainability

Cities are expected to provide capacity for their residents to enhance their potentials in economic affairs and draw business and capital. Nowadays with financial crises all over the world, economic sustainability should be essentially concerned. This crisis forced weaknesses in planning strategies and financial models of cities authorities to offer services and invest in infrastructures. By studying smart economies, Apostol et al. (2015) suggested that smart economies include directions and policies which motivate innovation in cooperation with advanced technology, academic research, and attention to a sustainable environment. Arroub, Zahi, Sabir, and Sadik (2016) mention smart economies as creativity, competitiveness, communication technologies, and using the information in all aspects of the economy as well as being responsible for exploiting resources (AlSharif, Pokharel, 2021).

Environmental Sustainability

Appio et al., 2019; Ismagilova et al. (2019) suggests that smart environment is engaged in controlling pollution, managing energy, smart networks, improving waste disposal, enhancing water and air quality, increasing green spaces, and monitoring radiation. It is so important for reducing the effect of city on an environmental resource by efficient and smart using technology and combining infrastructures. It could also have resulted in city flexibility against environmental shocks. Niˇzeti´c et al. (2020) show how IoT technologies could improve smart cities' waste management by for example in the concept of circular economy (AlSharif, Pokharel, 2021).

Inhabitant Sustainability

The Inhabitant sustainability of smart cities could be characterized by the rate of social engagement, being opened for different communities, growth of human resources, education, and deducting digital gaps. Everyone in smart cities must be provided by showing current and further needs, equal opportunities, and security (Dempsey, and et al. 2011, AlSharif, Pokharel, 2021).

Governance Sustainability

If the citizens in smart cities are engaged in decision making, co-production, using different public tools, technology merging, and exchanging data to make their life better, then Governance sustainability could be facilitated. It is critical for smart cities to merge ruling with social matters to have sustainable governance (Elkington, 2006).

It is pointed up to ruling and governing as a pillar in developing interactions between all factors of smart cities. Such electronic ruling could be improved by using 5G technologies, AI, and the Internet of things (IoT). It was also suggested by Ismagilova et al. (2019) to use cloud space for rendering information services which helps decision-making as it makes people to be engaged in sharing information (AlSharif, Pokharel, 2021).

Policy sustainability

Creativity in technology is an important step in policy sustainability. The policy sustainability of a smart city is defined by awareness of people, scientific advantage, theoretical correctness, environmental creativity, and applicability (Nill, Kemp, 2009; AlSharif, Pokharel, 2021).

Business Sustainability

It is facilitated business sustainability by integrating social, environmental, and economic requests and matters to insure moral, sustainable, and sound development (Dyllick, Muff, 2016).

MATERIALS AND METHODS

Data Collection

The statistical population of the quantitative section in the field of causal relationships between factors consisted of 42 urban management experts who were purposefully selected. Their selection criteria were teaching in urban management, a doctoral degree in civil engineering, urban management, urban planning, and research in this field.

Fuzzy DEMATEL

Fundamentals

DEMATEL technique is a group multi-criteria decision making which illustrates cause and effect relationship among criteria through a directional graph (Tseng, 2009). The fuzzy DEMATEL technique was applied to determine causal relationships among the criteria.

Step 1: A questionnaire with square matrices (a square matrix of order 7 for the main criteria) was prepared for pairwise comparison of the criteria.

Step 2: A 42-expert panel was invited to evaluate interrelations among the criteria by pairwise comparisons.

Step 3: The experts used ten linguistic variables to illustrate the degree of causality between the criteria. Linguistic variables and their corresponding triangular fuzzy numbers to define the degree of influence of criteria are shown in Tab 1.

Tab 1: Linguistic variables for the degree of influence of the criteria

Linguistic variables	Crisp Scale	fuzzy Scales
No influence (N)	0	(0,0,0)
Very low influence (VL)	1	(0,0,0.2)
low influence (L)	2	(0,0.25,0.5)
High influence (H)	3	(0.25,0.5,0.75)
Very High influence (VH)	4	(0.5,0.75,1)

After converting linguistic variables to triangular fuzzy numbers based on Table 2, the Initial direct-relation matrix for the kth expert was made as

$$\tilde{X}^k = \left[\tilde{X}_{ij}^k\right]_{n\times n} \quad k = 1, 2, \cdots, m; m = 42$$

and, n is the number of Criteria where i,j=1,2,⋯,n. Each element in matrix

$$\tilde{X}^k \ i.e.\ \tilde{X}_{ij}^k = \left(l_{ij}^k, m_{ij}^k, u_{ij}^k\right)$$

is a triangular fuzzy number that denotes the degree of the ith Criterion affects the jth Criterion when i≠j and, is equal to (0,0,0) when i=j.

Step 4: using the combination rule of fuzzy triangular numbers, i.e., equation 1 aggregated direct-relation matrix

$$\tilde{A} = \left[\tilde{a}_{ij}\right]_{n\times n} \quad (i, j = 1, 2, \cdots, n)$$

was achieved.

$$\tilde{a}_{ij} = \frac{1}{m}\left[x_{ij}^1 (+)\, x_{ij}^2 (+) \cdots (+)\, x_{ij}^m\right] \ (1)$$

Where (+) denotes Chen's fuzzy addition operation of triangular fuzzy numbers.

Step 5: Let

$\tilde{G} = [\tilde{g}_{ij}]_{n\times n}$ $(i, j = 1, 2, \cdots, n)$

be the normalized direct-relation matrix that was calculated by applying Equations 2 to 4.

Assume that each element in aggregated direct-relation matrix

$\tilde{A}$ is $\tilde{a}_{ij} = (l'_{ij}, m'_{ij}, u'_{ij})$ $(i, j = 1, 2, \cdots, n)$.

$$[\tilde{c}_i]_{n\times 1} = \left(\sum_{j=1}^{n} l'_{ij}, \sum_{j=1}^{n} m'_{ij}, \sum_{j=1}^{n} u'_{ij}\right) \qquad i = 1, 2, \cdots, n \tag{2}$$

$$c = \max_{1\le i\le n}\left(\sum_{j=1}^{n} u'_{ij}\right) \tag{3}$$

$$\tilde{G} = [\tilde{g}_{ij}]_{n\times n} = \left(\frac{\sum_{j=1}^{n} l'_{ij}}{c}, \frac{\sum_{j=1}^{n} m'_{ij}}{c}, \frac{\sum_{j=1}^{n} u'_{ij}}{c}\right) \qquad i, j = 1, 2, \cdots, n \tag{4}$$

Step 6: The total direct-relation matrix

$\tilde{S} = [\tilde{s}_{ij}]_{n\times n}$ $(i, j = 1, 2, \cdots, n)$

Where $\tilde{s}_{ij} = (l''_{ij}, m''_{ij}, u''_{ij})$

was calculated as follows:

By dividing $\tilde{G}$ and $\tilde{S}$ to three crisp matrices of their lower, middle and upper elements of fuzzy triangular number, $\tilde{S}$ can be obtained by using equations 5 to 7.

$$[l''_{ij}]_{n\times n} = [l'_{ij}]_{n\times n} \times \left([I]_{n\times n} - [l'_{ij}]_{n\times n}\right)^{-1} \tag{5}$$

$$[m''_{ij}]_{n\times n} = [m'_{ij}]_{n\times n} \times \left([I]_{n\times n} - [m'_{ij}]_{n\times n}\right)^{-1} \tag{6}$$

$$[u''_{ij}]_{n\times n} = [u'_{ij}]_{n\times n} \times \left([I]_{n\times n} - [u'_{ij}]_{n\times n}\right)^{-1} \tag{7}$$

where, I is the identity matrix of order n.

Step 7: The sum of each row and column of the total direct-relation matrix was stamped as two vectors

$\tilde{D} = [\tilde{d}_i]_{n\times 1}$, $(i = 1, 2, \cdots, n)$ and,

$\tilde{R} = [\tilde{r}_j]'_{n\times 1}$ $(j = 1, 2, \cdots, n)$

respectively. By adding $\tilde{D}$ to $\tilde{R}$ $(\tilde{D} + \tilde{R})$ "prominence" was made which indicates the importance of each criterion. Subtracting $\tilde{D}$ from $\tilde{R}$ $(\tilde{D} - \tilde{R})$ "relation" was obtained. Then, $= [d_i]_{n\times 1}$,$R = [r_j]'_{1\times n}$, $\vec{D} + \vec{R}$

and, $\vec{D} - \vec{R}$ vectors were defuzzified by Best Non-Performance (BNP) method.

When i=j ,if d_i>r_j→d_i-r_j>0 ,

then the criterion is a net cause;

When i=j ,if d_i<r_j→d_i-r_j<0 ,

then criterion is a net effect. d_i indicates the sum of direct and indirect effects of criterion i on other criteria. r_j indicates the sum of direct and indirect consisting of criterion j.

Step 8: A Cartesian coordinate system consisted of a horizontal axis $(\vec{D} + \vec{R})$ and a vertical axis $(\vec{D} - \vec{R})$ was drawn in which the coordinates of each criterion are displayed in ordered pairs (d_i+r_j , d_i-r_j).

Step 9: The impact relationship map for the criteria was drawn based on the defuzzified total direct-relation matrix. To demonstrate the most influential and influenced Criteria a threshold value is considered for criteria.

Tab 2: The fuzzy total direct-relation matrix ($\tilde{S}$) for the main Criteria.

Abb.	C01	C02	C03	C04	C05	C06	C07
C01	(0.062,0.209,0.39)	(0.018,0.265,0.477)	(0.062,0.254,0.458)	(0.146,0.279,0.466)	(0.08,0.319,0.53)	(0.333,0.502,0.68)	(0.109,0.311,0.514)
C02	(0.148,0.299,0.489)	(0.037,0.173,0.355)	(0.148,0.277,0.463)	(0.025,0.201,0.401)	(0.151,0.334,0.53)	(0.121,0.28,0.521)	(0.052,0.251,0.468)
C03	(0.063,0.179,0.408)	(0.141,0.3,0.488)	(0.063,0.146,0.328)	(0.035,0.123,0.352)	(0.068,0.269,0.488)	(0.331,0.438,0.632)	(0.22,0.333,0.518)
C04	(0.18,0.382,0.581)	(0.062,0.32,0.539)	(0.18,0.342,0.546)	(0.052,0.184,0.382)	(0.312,0.491,0.673)	(0.329,0.525,0.722)	(0.236,0.41,0.61)
C05	(0.058,0.245,0.441)	(0.14,0.289,0.472)	(0.058,0.157,0.373)	(0.018,0.181,0.382)	(0.06,0.197,0.381)	(0.307,0.426,0.613)	(0.086,0.191,0.417)
C06	(0.159,0.331,0.528)	(0.041,0.273,0.489)	(0.159,0.296,0.496)	(0.06,0.165,0.395)	(0.166,0.364,0.571)	(0.168,0.319,0.518)	(0.319,0.422,0.598)
C07	(0.042,0.244,0.441)	(0.013,0.224,0.43)	(0.042,0.151,0.371)	(0.139,0.258,0.431)	(0.06,0.274,0.479)	(0.187,0.377,0.578)	(0.069,0.186,0.365)

Tab 3: The crisp total direct-relation matrix (S) for the main Criteria.

		C01	C02	C03	C04	C05	C06	C07
Abb.	Criteria	Policy	Economic	Environmental	Governance	Social	Inhabitant	Business
C01	Policy	0.221	0.253	0.258	0.297	0.310	0.505	0.311
C02	Economic	0.312	0.188	0.296	0.209	0.338	0.307	0.257
C03	Environmental	0.217	0.310	0.179	0.170	0.275	0.467	0.357
C04	Governance	0.381	0.307	0.356	0.206	0.492	0.526	0.419
C05	Social	0.248	0.300	0.196	0.194	0.213	0.449	0.232
C06	Inhabitant	0.339	0.267	0.317	0.207	0.367	0.335	0.446
C07	Business	0.243	0.222	0.188	0.276	0.271	0.381	0.207

Tab 4: The sum of rows ($\tilde{D}$) and the sum of columns ($\tilde{R}$) for fuzzy total-relation matrix and their corresponding crisp values for main Criteria

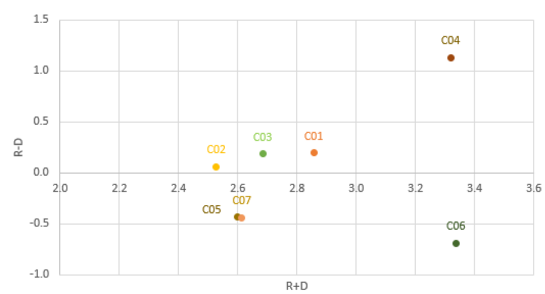
Abb.	Criteria	D~ in triangular fuzzy form	R~ in triangular fuzzy form	D~ in crisp form	R~ in crisp form
C01	Policy	(0.812,0.713,1.525)	(0.099,2.14,1.889)	2.16	1.96
C02	Economic	(0.683,0.451,1.134)	(0.231,1.815,1.845)	1.91	1.85
C03	Environmental	(0.922,0.713,1.635)	(0.209,1.789,1.623)	1.98	1.79
C04	Governance	(1.352,0.476,1.827)	(0.876,2.654,1.391)	2.69	1.56
C05	Social	(0.728,0.897,1.626)	(0.169,1.687,2.247-)	1.83	2.27
C06	Inhabitant	(1.071,1.777,2.848)	(0.706,2.168,2.867-)	2.28	2.97
C07	Business	(0.553,1.093,1.646)	(0.54,1.714,2.105-)	1.79	2.23

Tab 4: The "Prominence" and "Relation" values in the form of triangular fuzzy and crisp numbers for main Criteria

Abb.	Criteria	D~+ R~	D~-R~	(D~ + R~)	(D~ - R~)	Category
C01	Policy	(0.251,0.251,3.515)	(3.279,6.793,0.236)	2.856	0.195	net cause
C02	Economic	(0.03,3.227-,0.03-)	(0.023-,3.25,6.478)	2.527	0.060	net cause
C03	Environmental	(0.166,0.166,3.215)	(3.036,6.25,0.179)	2.684	0.185	net cause
C04	Governance	(1.263,1.263,4.054)	(2.811,6.866,1.243)	3.319	1.127	net cause
C05	Social	(0.56,3.08-,0.56-)	(0.573-,3.652,6.732)	2.599	0.434-	net effect
C06	Inhabitant	(0.698,3.596-,0.698-)	(0.669-,4.264,7.86)	3.336	0.691-	net effect
C07	Business	(0.39,3.095-,0.39-)	(0.395-,3.49,6.585)	2.613	0.442-	net effect

RESULT AND DISCOTION

By gathering expert opinion using the pairwise comparisons matrix for the Criteria the linguistic variables were converted to triangular fuzzy numbers. The experts' opinions were combined by using Equation (1). Then, the normalized direct-relation matrix, fuzzy, and crisp total direct-relation matrix was calculated. The fuzzy and, crisp total direct-relation matrix for main Criteria is illustrated in TTables 2, 3 respectively.



Tab 1: The causal diagram from the crisp data for main Criteria

A threshold of 0.221 obtained from the first Quartile of all elements of the total relation matrix, is considered to indicate the strongest interdependence among criteria. As Tables 4 and 5 shows, Policy factors affect all six other factors and are influenced by all the other factors except Environmental factors. Governance factors influence all six other factors, and are affected by Policy and Business factors. Economic factors affect all the other factors except Governance factors. Environmental factors are affected by four other factors (Policy, Economic, Governance, Inhabitant).

Criterion (C06) Inhabitant factors has the most interaction (influence/influence) with other criteria and since (D_i-R_i) is negative for Inhabitant factors, so this criterion is a net effect.

Criterion (C04) Governance factors after Inhabitant factors has the most interaction (impact/influence) with other criteria and since (D_i-R_i) is positive for Governance factors, so this criterion is a net cause. Given that the value (D_i-R_i) is positive, the criteria of Policy factors, Economic factors and Environmental factors are also net causes. Figure 2 shows the causal diagram from the crisp data for the main Criteria

CONCLUSION

Nowadays, people use the term "Smart City" all over the world with different concepts and from different practical aspects. Most of them use it when IT is applied in urban development and citizens' life. More than this, the term "Smart City" is referred to changes in technological infrastructures in conversion from a traditional industrial society to an academic one. Among social, economic, environmental, Inhabitant, Governance, policy, and business sustainability, the last one affects all others and also being affected by all others except environmental. Governance sustainability affects all other factors and is affected by policy and business ones. Economic sustainability affects all other factors except Governance. Environmental sustainability is affected by four of them, i.e., economic, Governance, Inhabitant, and policy.

The smart economy is turning one of the pillars of smart cities as economic movements in the information world is a serious key in the improvement of a city. It should be also able to make people from inside and outside the city engage in social matters and also attract companies and investors to accelerate development. A smart economy is a creative and innovative practice for governing such cities.

Criterion Inhabitant factors has the most interaction (influence/influence) with other criteria and since (D_i-R_i) is negative for Inhabitant factors, so this criterion is a net effect.

Criterion Governance factors after Inhabitant factors has the most interaction (impact/influence) with other criteria and since (D_i-R_i) is positive for Governance factors, so this criterion is a net cause. Given that the value (D_i-R_i) is positive, the criteria of Policy factors, Economic factors and Environmental factors are also net causes.

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