Sustainable Cities and Society 37 (2018) 608–618

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

A methodological framework for assessment of ubiquitous cities using ANP and DEMATEL methods

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ARTICLE INFO

Keywords:
Ubiquitous city
Smart city
Ubiquitous coefficient
Analytical network process (ANP)
Decision-Making trial and evaluation laboratory (DEMATEL)

ABSTRACT

The increasing development of civilization is one of the important issues exacerbating urban problems, such as pollution, poor sustainability, and weak security. The creation of ubiquitous cities (u-city), with intelligent convergence systems, is a solution to overcoming these problems. The u-city is at a more advanced level than a smart city, and building a smart city is a step toward the u-city. Thus, this study develops an effective framework to determine the required platform toward establishing a u-city by explores the main components of a smart city, such as citizens, environments, and key infrastructures, and the criteria to measure each component. The interaction between the components and their criteria, are specified using the Analytical Network Process (ANP) and the Decision-Making Trial and Evaluation Laboratory (DEMATEL) methods Finally, according to the weights obtained, a ubiquitous coefficient for a city is proposed. In this study, the u-coefficients for Tehran, Iran and Seoul, South Korea are obtained (45% and 92%, respectively), which verify the accuracy of the suggested framework for determining ubiquitous conditions of cities. Tehran has the highest weights in the basic components (citizens and governments) and it needs to invest in building a ubiquitous infrastructure in transportation, healthcare, and the economy.

1. Introduction

In recent years, there has been an increasing trend in the migration of large number of people to urban areas. It is forecasted that more than 60% of the population will live in an urban environment by 2030 (Gaur, Scotney, Parr, & McClean, 2015). Globalization, urbanization, and industrialization have been recognized as three important drivers leading human civilization to the overpopulation of cities and its consequent problems, such as inadequate public transportation, pollution, poor sustainability, weak security, and slow business generation (Abellá-García, Ortiz-de-Urbina-Criado, & De-Pablos-Heredero, 2015), that requires cities to compete for resources to increase their citizens' quality of life (Belanche, Casaló, & Orús, 2016).

The above intractable problems make an urgent need to develop and apply innovative solutions and sophisticated methods in the field of urban planning and design (Bibri and Krogstie, 2017).One of the approaches taken for dealing with the problems caused by urbanization is to move toward the creation of ubiquitous cities (u-cities), which can be operationalized through ubiquitous computing, in which computing technology becomes nearly invisible by being embedded into every objects (Lee et al., 2007), and helps to improve the quality of services. Weiser (1993) has been recognized as a pioneer who proposed 'Ubiquitous Computing' project at the Xerox Palo Alto Research Centre in the US, constructing an environment in which "digital networks and devices link individual residents not only to other people but also to goods and services whenever and wherever they need". Ubiquitous means having access to any data or services at any time and in any place via any device through any network. It includes various technologies to connect seamlessly the physical objects of the real world (Hashemi and Sadeghi-Niaraki, 2016; Jung, Pyeon, Koo, & Kim, 2008). A u-city can, therefore, be broadly defined as a city which operates beyond time and space (Hyang-Sook, Byung-Sun, & Woong-Hee, 2007). In a u-city, digital devices such as computers will become elements of an environment in which any user can continually interact with hundreds of interconnected digital devices (Weiser (1993)) at anytime and anywhere and therefore be able to make decision based on the available information, just like a human. sensors and actuators are embedded into the physical environment (e.g., traffic lights, and parking lots) and various personal devices (e.g., smart phones, and computers), and all these entities are connected via digital networks which often provides

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https://doi.org/10.1016/j.scs.2017.11.024
Received 4 July 2017; Received in revised form 19 November 2017; Accepted 19 November 2017
Available online 23 November 2017

services such as location-based services (Jamali, Sadeghi-Niaraki, & Arasteh, 2015; Maass and Varshney, 2012). The concept of the u-city could enhance the urban economy by embedding information and communication technologies (ICT) in municipal infrastructure and urban facilities and, for instance, help to reduce wasting resources and time (Yigitcanlar and Lee, 2014).

It is worthy to note that the concept of the smart city differs from that of the u-city. In a smart city, traditional urban services are replaced by electronic services, and the use of programmable devices becomes more common, but in a u-city, too many sensors are embedded into the fabric of daily life and smart devices are interconnected on network enables anyone in any place with any device at any time do anything desired. So, generally, the u-city is at a more advanced level than the smart city, and building a smart city is one step toward a u-city.

Despite the importance of this issue, there are few discussions in academic literature on the relevant theory and/or frameworks (Yigitcanlar and Lee, 2014); basic elements and their interrelationships are still ambiguous and there is no reliable framework for the comparisons. On the other hand, the required technologies span multiple fields and cannot be effective without integration and relationship analysis. So, in order to fill the aforementioned gaps, this research aims to develop an operational framework for the evaluation of city's level of smartness through determining the main components of a smart city and their interactions. To do so, first, the main components of a smart city (e.g., citizens, governments, homes, environments, power networks, water networks, transportation networks, health, security, the economy, and the education systems) and the criteria to measure them are determined; then, the interactions and degree of importance of each component are specified using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method and the Analytical Network Process (ANP), and according to the weights obtained, a ubiquitous coefficient (u-coefficient) is calculated which shows the current ubiquity state of a city. Finally, to evaluate the accuracy of our proposed framework, the u-coefficients for Tehran (Iran), as our case study, and Seoul (South Korea), as a pioneer in this field, are calculated and compared.

Section 2 reviews the most relevant studies on smart and ubiquitous technologies for determining a framework to make a smart city and a u-city. Section 3 determines and describes the components of a smart city and criteria for each one. The ubiquitous criteria of each component and the results of implementing ANP and DEMATEL on the framework are presented in Section 4, where the u-coefficient for Tehran is also calculated as a case study. Section 5 covers the evaluation process of the proposed framework by calculating the u-coefficient for Seoul and also discussion about the results. Finally, the paper concludes by summarizing the contribution of this study and addressing existing challenges which requires future works in Section 6.

2. Literature review

Several smart documents are drafted for a number of large cities (e.g. Bilbao, Spain; Seoul, South Korea; London, England; and Chicago, USA) that describes local projects and infrastructures to achieve a smart city. Also, several conceptual and strategic models have been provided discussing how to design and develop smartness in cities (Angelidou, 2014). Although smart cities represent a conceptual urban development model based on the utilization of human, collective, and technological capital to enhance development and prosperity in urban agglomeration, strategic planning for development still remains a rather abstract idea for several reasons, including the fact that it refers to largely unexplored and interdisciplinary fields. For this reason, (Angelidou, 2014) reviewed the factors that differentiate policies for the development of smart cities in an effort to provide a clear view of the strategic choices that come forth when mapping out such a strategy. A range of strategies for smart city development, from national to local, new versus existing, hard versus soft infrastructure, to economic sector-based versus geographically based strategies, have been mentioned in the research, and it has finally been noted that cities should identify their priorities and commence development based on their needed infrastructure.

Nam and Pardo (2011) offered strategic principles aligning to the three main dimensions (technology, people, and institutions) of smart city: integration of infrastructures and technology-mediated services, social learning for strengthening human infrastructure, and governance for institutional improvement and citizen engagement. This research has also explored the practical implications of the conceptual model suggested (Nam and Pardo (2011)).

Lee et al. (2014) studied six key conceptual dimensions (i.e., urban openness, service innovation, partnerships formation, urban proactiveness, smart city infrastructure integration, and smart city governance) and 17 sub-dimensions of smart city practices. They combined these perspectives in a conceptual framework highlighting the processes for building a smart city and used Seoul metropolitan city and San Francisco as two case studies. They also reported eight ‘stylized facts’ needed to develop a sustainable smart city (Lee, Hancock, & Hu, 2014).

Monfaredzadeh and Krueger (2015) aimed to improve the social sustainability of cities by providing a particular conceptual focus on the potential of smart city strategies. A measurement framework of social sustainability was suggested, and the attributes were also mentioned. They also emphasized the fact that a city will be smart to when responding to the needs of the population without covering ultra-wideband (Monfaredzadeh and Krueger, 2015).

Shin (2009), assessing qualitative data related to the South Korean u-city projects, highlights the need for a comprehensive approach to integrate ‘technological possibilities’ with ‘social application needs’ as the key challenge of such projects (Shin, 2009). Qualitative indicators for smart city business models were also discussed by Walravens (2015). That research starts from an established business model framework and expands it to include an additional set of indicators required to successfully perform a qualitative analysis of the business models for new (digital) services offered by cities (Walravens, 2015).

Security and privacy challenges in a smart city were studied by (Elmaghraby and Losavio, 2014) and (Bartoli et al., 2011). Security includes preventing illegal access to information and fending off attacks causing physical disruptions in service availability. As digital citizens have more and more personal devices that provide data about their locations and activities, privacy seems to be at risk. These studies summarized the key challenges (e.g. privacy, networking connectivity, complexity, security services, sensitive data organization, etc.), emerging technology standards such as IEEE[1] (http://www.ieee.org/) and IETF[2] (http://www.ietf.org/), and issues to be watched for in the context of privacy and security in smart cities, and also presented a model representing the interactions between people, servers, and things. Those are the major elements in the smart city, and their interactions must be protected.

Bhunia et al. (2014) proposed fuzzy-assisted data gathering and an alert scheme based on the Internet of Things (IoT) for healthcare services in a smart city (Bhunia, Dhar, & Mukherjee, 2014). A smart waste collection/management system was discussed by (Digiesi, Facchini, Mossa, Mummolo, & Verriello, 2015) and (Gutierrez, Jensen, Henius, & Riaz, 2015). Digiesi et al. (2015) proposed a decision support system to help public administrators at the municipal level to design and plan an integrated waste management system to minimize net carbon emissions (Digiesi et al., 2015). Gutierrez et al. (2015) presented a waste collection solution, using intelligent trash cans, and an IoT prototype embedded with sensors to read, collect, and transmit trash volume data over the Internet(Gutierrez et al., 2015). Sharif and Sadeghi-Niaraki (2017) states a survey for ubiquitous sensor network simulation and

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[2] Internet Engineering Task Force.