Expert Systems with Applications 41 (2014) 5625–5635

Contents lists available at ScienceDirect

Expert Systems with Applications

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

Algorithm-embedded IT applications for an emerging knowledge city: Istanbul, Turkey

Melih Bulu [a,*], Muhammed Ali Önder [b], Vural Aksakalli [b]

[a] Department of Management, Istanbul Sehir University, Kuşbakışı Caddesi No: 27 Altunizade Üsküdar, 34662 Istanbul, Turkey
[b] Department of Industrial Engineering, Istanbul Sehir University, Kuşbakışı Caddesi No: 27 Altunizade Üsküdar, 34662 Istanbul, Turkey

ARTICLE INFO

Keywords:
Algorithm-embedded information technology application
Information technology
Decision support system
Expert system
Knowledge city
Istanbul

ABSTRACT

As city resources around the world begin to stretch beyond capacity due to ever-increasing population, a major challenge for an emerging knowledge city is to maintain high-quality living conditions for its residents. It is therefore imperative existing city infrastructural resources are used in an optimal manner by minimizing cost and maximizing utility. Such infrastructural resources include transportation networks, electricity, water and natural gas lines, sewers, and waste sites. To that end, algorithm-embedded information technology tools have proven to be tremendously useful for city decision makers, and technologies using algorithm-embedded systems are being used more frequently than ever before. In particular, as one of the emerging knowledge cities in the world, Istanbul has been deploying such applications at various levels for better use of the city's resources. The purpose of this study is two-fold: classify algorithm-embedded information technology application areas related to management of infrastructural resources in a city in a systematic way, and; provide an up-to-date review of each application area and investigate the level of algorithm-embedded information technology use in Istanbul. The study has implications for the city officials as well as officials of other emerging world knowledge cities regarding the use of existing algorithm-embedded information technology tools in their cities.

1. Introduction

It is estimated by 2050, about 70% of the world's population will be living in cities (Lederborgen et al., 2011). Thus, efficient city resource management has become a top priority in world's knowledge cities. As stated in Yigitcanlar, O'Connor, and Westerman (2008a) and Ergazakis, Metaxiotis, and Psarras (2004), these resources include hard as well as soft infrastructures in the broad context of knowledge-based urban development policies. Clearly, a functional hard infrastructure system is a prerequisite for an efficient and effective soft infrastructure, both of which are vital for economic and spatial development of knowledge cities (Yigitcanlar & Lonnqvist, 2013). Nevertheless, actual models, tools, and cases in the emerging field of knowledge-based development are still scarce (Yigitcanlar, 2010). Besides, especially in cities with inadequate infrastructural resources, the limits of city resources will soon be reached and living conditions will deteriorate considerably. Thus, providing high-quality living conditions will become an even more challenging task for the world's developing knowledge cities in the near future. Developed knowledge cities already have well-working infrastructure. Therefore, it is easy to provide high-quality living conditions in these cities for citizens. On the other hand, this is not the case in emerging knowledge cities. Emerging knowledge cities should be dealing with the improvement of city infrastructure as one of their priorities (Yigitcanlar, 2009).

Today's emerging knowledge cities should not only deal with the improvement of soft infrastructures such as knowledge base, industrial infrastructure, quality of life, urban diversity, social equity (Van Winden, Van den Berg, & Pol, 2007), but also hard infrastructures such as transportation, energy and water distribution, waste and sewage collection, and so on. An emerging knowledge city can survive if it is able to improve its infrastructure, otherwise a knowledge city will face significant threat.

Knowledge workers are the main backbone of a knowledge city (Yigitcanlar, Velibeyoglu, & Martinez-Fernandez, 2008b). They work in consultancy, law, engineering, and design companies; they are the decision makers in the management level of organizations. Members of the academia can also be categorized as knowledge workers. Without them, a city could not survive as a knowledge city. Therefore, providing a livable environment to knowledge workers is of vital importance (Edvinsson, 2006). Knowledge workers should

* Corresponding author. Tel.: +90 505 838 3838.
E-mail addresses: melihbulu@sehir.edu.tr (M. Bulu), muhammedonder@std.sehir.edu.tr (M.A. Önder), aksakalli@sehir.edu.tr (V. Aksakalli).

http://dx.doi.org/10.1016/j.eswa.2014.02.013
0957-4174/

not spend their time due to inefficiencies of the city's infrastructure. Therefore traffic congestions, electricity breakdowns, water shortages, sewage and waste collection problems can affect a knowledge workers' productivity negatively in their business life. These kinds of inefficiencies will create extra cost not only for knowledge workers but also for the companies using these skilled human resources. If the city's infrastructure creates significant inefficiencies for knowledge workers, not only knowledge workers may decide to migrate to another city with better infrastructure, but also companies which are using those knowledge workers as well (Bulu, 2013).

The task of maintaining acceptable living standards in knowledge cities can be achieved by two means: (*i*) build new infrastructure and provide new services or (*ii*) improve the utilization rate of existing infrastructure and city facilities. Due to lack of physical space and qualified personnel as well as inadequate funding, building new infrastructure and providing new services is not always a feasible option. Therefore, it is of utmost importance to maximize the use of existing city infrastructural resources such as transportation networks (e.g., roads, railways, and metro lines), electricity, water and natural gas lines, sewage systems, and waste sites. This maximization, however, is not a straightforward task. There are numerous performance metrics and stakeholders for any given city service or facility. Nonetheless, recent advances in computing power, sensor technology, new methodologies for storing and processing large amounts of data, and the wide-spread use of the Internet has opened a vast window of opportunity for optimization of virtually all resources used in a city. Putting these information technology tools to use for better use of a city's resources is a particularly exciting new area for researchers as well as practitioners.

Of particular interest is Istanbul, which is an attractive metropolitan city home to more than 14 million people living in a very dense region. The population of the city quadrupled in the last three decades with inadequate planning and minimal infrastructural investments, all of which have resulted in an extraordinary burden on the city's infrastructural resources. Even though the city is faced with various problems due to immigration, Istanbul is trying to upgrade itself by using available opportunities. According to Bulu (2011), Istanbul is the most competitive city of Turkey. Istrate, Berube, and Nadeau (2012) study shows Istanbul is the seventh in the world with respect to growth rate index composed of income and employment variables. Istanbul is therefore one of those metropolitans where algorithm-embedded information technology (AEIT) (or IT tools in general) hold a tremendous potential for better use of the city's resources, facilities, and services.

The purpose of this study is to present a brief yet up-to-date review of AEIT tools aiming to improve use of existing city infrastructural resources, classify them in a systematic manner for further studies, and analyze Istanbul in these areas. Our goal is to illustrate that AEIT tools are a viable approach for easing the pressure of ever-increasing city populations on already stretched city infrastructure, facilities, and services, and determine the advantages and disadvantages of Istanbul in the use of such AEIT applications.

Our focus in this work is on "algorithm-embedded" IT applications, which specifically encompass any IT solution containing at least one algorithmic component. Such algorithms typically include the following: artificial intelligence, image processing, pattern recognition, prediction and forecasting, mathematical optimization, case-based reasoning, and expert or decision support systems. Our definition of AEIT applications particularly excludes systems that merely collect, summarize, and/or present existing data. Our purpose with this limitation to algorithm-embedded applications is to stay within the confines of the knowledge city paradigm. Another aspect of our study is it is limited to the systems used for increasing efficiency and effectiveness of infrastructural resources of a city. Specifically, in order to keep our analysis at a reasonable complexity, we excluded the following city resources from consideration: telecommunication systems, health and education facilities such as public hospitals and schools, airports, and safety issues not directly related to preservation of infrastructural resources. The reason for this exclusion is our point of view this work is primarily from a city municipality perspective, and those resources, at least in the case of Istanbul, are managed by private companies (telecommunication systems, airports) or other government agencies (public hospitals and schools). Thus we confined our research under five titles. These are (*i*) transportation, (*ii*) energy, (*iii*) city infrastructural safety, (*iv*) water management, and (*v*) waste management.

Our work is novel on two fronts. First, to our knowledge, it is the first of its kind to unify existing knowledge city applications by taking the rather unique approach of combining them under the umbrella of algorithm-embedded information technology applications. Second, we are not aware of any previous studies providing a comprehensive review and summary of existing AEIT applications in the City of Istanbul.

The rest of this manuscript is organized as follows: Section 2 presents reviews of AEIT applications in the literature as well as in the industry. Section 3 presents Istanbul as a case study for AEIT applications. Section 4 concludes our study, including our recommendations for Istanbul in light of the applications around the world as well as our suggestions for other metropolitans that might potentially benefit from the current AEIT applications in Istanbul. Several directions for future research are also discussed in Section 4.

2. Literature review

With the advance of technology, millions of digital devices are producing data about virtually all aspects of city life. All this information can be turned into knowledge, either by a trained professional or by an algorithm-embedded information technology application. With the aim of acquiring this knowledge and making efficient decisions to increase quality of life for citizens, researchers have proposed various approaches and methodologies in the literature and private sector companies such as IBM, Ericsson, CISCO, and NEC have been working with city governments in developing AEIT applications. This section reviews such AEIT studies in the literature and applications in the industry for each one of the five broad application areas identified above.

2.1. Transportation

Increasing population and travel needs of residents in cities are making the traffic conditions worse. The potential solution for this problem is to manage the traffic intelligently. The most popular area in traffic management is traffic light control, on which many studies were carried out and many applications were developed. De Schutter (1999) from Netherlands developed a traffic light control algorithm for a single intersection. Wiering, Veenen, Vreeken, and Koopman (2004) designed an intelligent traffic light control system and demonstrated its performance. Regarding traffic control systems other than traffic light control, Wen (2010) presented an intelligent traffic management system with Radio Frequency Identification (RFID) technology that can be used in other areas such as tracing criminals and traffic speed prediction.

Regarding public transportation, there are many studies and algorithms to optimize travel times and routes. With the aim of time efficiency, Chien, Ding, and Wei (2002) predicted bus arrival times with an artificial neural network algorithm and Bin, Zhongzhen, and Baozhen (2006) did a similar study using support vector machines. Liu, Pai, Chang, and Hsieh (2001) developed a path-planning algorithm to improve route efficiency. Planning