Supporting the solution selection for a digital city with a fuzzy-based approach

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Abstract: Digital cities have been evolved in various forms around the world. They are entitled wireless/smart/digital/ubiquitous, and they structure significant areas of practice of metro-networks and large-scale information systems. Recently, ubiquitous computing is being applied in city areas, suggesting real-time interaction between the physical and the digital space. However, digital cities are complex and of high risk projects and their sustainability is not guaranteed. This paper focuses on the development of a selection system for various solutions available for a digital city. It considers available solutions the information systems that have been applied successfully in existing cases, and a fuzzy-based model for their selection. The model considers a group of stakeholders/supervisors that applies a number of different-weighted selection criteria on numerous information systems, in order to define the requirements of a digital city planned project. The proposed approach could support the design of sustainable digital cities with democratic and effective decision making.

1 INTRODUCTION

Digital cities have evolved from their initial web form of *America-On-Line* in the early '90s (Wang and Wo, 2001) to the recent ubiquitous spaces of *Korea* (Hyang-Sook, Byung-Sun and Woong-Hee, 2007). These modern ecosystems are entitled digital/smart/wireless/broadband/ubiquitous cities, they demand extensive information systems and city-wide broadband networks to operate and to deliver smart services to the habitants. These kinds of services are oriented to various daily social activities such as public and e-commerce transactions, transportation, parking, e-deliberation, e-health, e-learning, kid safety etc. Moreover, smart environments at home, at work and at school offer habitants opportunities to access information and services from everywhere to anyone.

Literature shows that all various digital cities face common challenges (Anthopoulos and Fitsilis, 2010; Anthopoulos and Fitsilis, 2009), against which they apply different solutions based on information and communication technologies (ICT). Today, ubiquitous technologies support local Governments in urban planning (Lee, Oh, and Jung, 2009; Lee and Oh, 2008) via collecting, assessing and visualizing information collected from the urban space.

However, although digital cities appear as the future cities' form, they demand extensive funding, and significant argument (New Millenium Research Council, 2005) questions their sustainability and necessity. Moreover, a digital city project is complex and concerns a global range of the activities in a city. In this context, standardization and architecture were considered as suitable methods and an Enterprise Architecture (EA) framework with a proper *sustainable architecture* has been proposed (Anthopoulos and Fitsilis, 2010).

This paper considers that the architectural standards are not enough to lead local Governments in effective digital city design, and in successful and sustainable implementation. In this context, a requirements engineering method that is based on *intuitionistic fuzzy sets* (Atanassov, 1986) is used to derive a ranking for the selection between various ICT solutions suitable for digital cities. Although requirements engineering methods have been proposed for digital cities (Doukas et al., 2011) our approach differentiates by considering the degree of unawareness when evaluating the suitability of different ICT solutions, which is known to be an uncertain element (Kitchenham, Pfleeger, 1996).

Moreover, our approach allows the supervisor of a digital city to interpret measurable attributes, which are available from existing cases, according to individual case's requirements. Intuitionistic fuzziness is used for solution selection, for the following reasons:

a) Solution's suitability indices can be characterized differently for different cities (e.g. a range of a metro-WiFi, can be considered very satisfactory for a big city and extremely unsatisfactory for a small one).

b) Suitability indices (e.g. population, system's maintenance cost etc.) cannot be attributed with certainty to high-level suitability parameters (e.g. service availability, stability etc.).

c) Supervisors could be sceptical against (a) and (b) due to return of investment (ROI), earned value and applicability in the city.

d) Given a potentially large number of solutions, there is a need to efficiently derive a short list of candidate or prerequisite co-selected solutions before preceding to a more precise evaluation (for instance, an intelligent transportation systems demands the existence of a WiFi or UHF network to operate).

In section 2 of this paper, an introduction to digital city services and to intuitionistic fuzzy sets are presented, and our approach for solution selection based on intuitionistic fuzzy sets is described. Then in section 3 our method is explained, while in section 4 related work is compared and future research dimensions and conclusions are considered.

2 BACKGROUND

Various digital city challenges are approached by different ICT-based solutions. Literature (Anthopoulos et al., 2010, Kim et al., 2010) provides useful information of various digital city cases and of the installed ICT based solutions. This analysis provides important information about the potential ICT solutions that can be applied in a digital city.

On the other hand, an IFS named A in a finite set named X can be defined as (Atanassov, 1986):

$$A = \{< x, \mu_A(x), v_A(x) > | x \in X\} \quad (1)$$

where:

$$\mu_{\mathrm{A}} : X \rightarrow [0,1] \quad (2)$$

$$v_{\mathrm{A}} : X \rightarrow [0,1] \quad (3)$$

$$0 \le \mu_{\mathrm{A}}(x) + v_{\mathrm{A}}(x) \le 1 \quad \forall x \in X \quad (4)$$

The functions $\mu_{\mathrm{A}}(x)$ and $v_{\mathrm{A}}(x)$ denote respectively the degree of membership and non-membership of x to A. For each Intuitionistic Fuzzy Set (IFS) A in X,

$$\pi_{\mathrm{A}}(x) = 1 - \mu_{\mathrm{A}}(x) - v_{\mathrm{A}}(x) \quad (5)$$

is called the hesitation degree of whether x belongs to A. The smaller the hesitation degree is, the more certain the knowledge of whether x belongs to A is; on the other hand, the bigger the hesitation degree is the more uncertain the respective knowledge is. In this context, an ordinary fuzzy set can be written as:

$$\{< x, \mu_A(x), 1 - \mu_A(x) > | x \in X\} \quad (6)$$

This paper's approach uses linguistic terms (Table 1) to express both the uncertainty about the values of the solutions' indices, and the uncertainty about the impact of each solution's index on the required system's suitability parameters. For example, an Intuitionistic Fuzzy Number (IFN) [0.7, 0.2, 0.1] represents membership μ = 0.7, non-membership v = 0.2 and hesitation degree π = 0.1. This IFN could characterize the total suitability of a digital city solution as important. The value of 0.7 stands for agreement to this characterization, 0.4 with disagreement and 0.1 as hesitation between these two opinions. These characterizations can be expressed by the supervisor during solution's selection in a particular domain.

Table 1: Linguistic terms used during evaluations

Linguistic Terms for the evaluation of solution's suitability index	**Intuitionistic Fuzzy Numbers (IFNs)**			**Linguistic Terms for the evaluation of the impact that suitability index has on suitability parameter**
	M	*v*	*Π*	
Very Important (VI)	0.9	0.1	0.0	Very Strong Impact (VSI)
Important (I)	0.7	0.2	0.1	Strong Impact (SI)
Medium (M)	0.5	0.4	0.1	Medium Impact (MI)
Negative (N)	0.3	0.6	0.1	Low Impact (LI)
Very Negative (VN)	0.1	0.9	0.0	Very Low Impact (VLI)

Moreover, this approach can be analyzed in the following steps:

Phase A) *During solution's determination*:

Each ICT solution is calculated by appropriate indices (e.g. landscape, number of potential users, maturity, prerequisites etc.) to derive values for the suitability of the solution.

Phase B) *During solution's selection*:

The supervisor characterizes each of the above indices with linguistic terms (Table 1). Then, distance measures provided by the intuitionistic fuzzy domain (described in the following Section) are derived to characterize the suitability of each available ICT solution.

3 METHOD DESCRIPTION

In order to compare the results of the proposed method with other approaches, the available solutions extracted from various digital city cases will be applied. The authors from their experiences from the digital city of Trikala case (Anthopoulos and Tsoukalas, 2005) propose a number of ICT solution suitability indices: extensibility (EXT), service availability (SA), citizen satisfaction (SS) and prerequisite systems (PR). The authors performed calculations on these indices using data from the Special Secretary responsible for the Greek e-Strategy (Greek Special Secretariat for the Information Society, 2008) and ten (10) sets of projects in Greek cities. The output of this work provides an average and a standard deviation for each solution and each suitability index. The potential ICT solutions concern (a) local digital public services (LDPS); (b) intelligent transportation (ITR); (c) e-health (EH); (d) e-tourism (ETR); and (e) e-learning (ELR) services. Via this method, authors finally characterize the suitability of these solutions with linguistic terms, according to their particular application domain and to the individual challenges of a digital city. Then, for each of these solution, the supervisor interprets the results and provides subjective judgments on the degree that each solution satisfies the suitability indices. According to measurements and to judgement for the particular case, the supervisor assigns the linguistic values for the impact of an index to the selection of an ICT solution (Very Important, Important, Medium, Negative, Very Negative) which are encoded in the respective IFNs of Table 1. Same interpretation procedure has to be followed for all of the suitability indices.

The next step in the selection process is to evaluate the impact of each ICT selection index to some index parameters of interest. For the purposes of this paper, these index parameters are (a) Reliability, (b) Usability, (c) Accuracy, (d) Extendibility and (e) Stability. It is hypothesized that these parameters are useful for the particular case (digital city) to the supervisor. Depending on the particular case, these index parameters could be defined properly. The supervisor assigns linguistic valuations on the degree that each parameter impacts positively the corresponding selection index. With this method, the digital city's requirements are quantified.

Then the distance of each solution concerning the considered set of parameters can be calculated. In particular, the distances can evaluate the applicability of each candidate solution according to the pre-defined set of criteria. The intuitionistic Hamming distance and the intuitionistic Euclidean distance can be applied for the calculations of the required values. Both distances have been determined as reliable since they consider not only membership and non-membership, but also the hesitation part of IFNs (Szmidt and Kacprzyk, 2000). Euclidean distance is useful when the Hamming distance results in a tie.

This method is suitable to support the selection procedure. In real-world scenarios it is quite possible that the number of ICT solutions, suitability indices and index parameters will be more and differentiated. However, the effectiveness of the calculations can be useful for the supervisor to structure a short list of candidate ICT solutions and then apply a more exhaustive examination of their applicability in the particular digital city case.

4 CONCLUSIONS, FUTURE WORK

The development of a digital city varies according to particular local and regional requirements. Different approaches have been proposed for the selection of the proper ICT-based solutions for an individual city case: a generic implementation model has been proposed by (Anthopoulos, Tsoukalas, 2005) that defines important perspectives for the identification of local needs and of the appropriate ICT-based solutions. Moreover, (Anthopoulos, Fitsilis, 2010) defined an EA that standardizes the requirements and the procedures for solution selection. Finally, (Moon, Heo, Heo, 2010) define a participation model for U-city planning and for u-city service selection, where the ICT-based solutions align to u-city vision and the procedure follows participatory design.

The proposed method of this paper aims to enhance decision making procedures concerning the ICT-based solution selection for a digital city. The method was based on intuitionistic fuzzy distances inspired by a medical case (Szmidt and Kacprzyk, 2000). It can enhance the selection procedure that supervisors can follow under the implementation of a digital city. It considers that the ICT-based solutions that have been applied in a digital city are not definitely suitable for all cases, since each individual case has its own particular differences, varying according to geographical, local and other characteristics. Moreover, the selection of an ICT-based solution has significant impacts on the sustainability of a digital city. In this context, a model is proposed that evaluates each available ICT-based solution according to suitability indices. Each index has been previously justified for the significance of its contribution in the selection method, via linguistic based terms that can be easily determined and used by the supervisors.

The proposed method is under testing on data collected from 10 sets of projects from different cities in Greece. Data was retrieved from the Greek Information Society Framework Program's Observatory (www.observatory.gr). The initial execution extracted useful outcomes that can be used for digital city's effective implementation and sustainability.

Future thoughts concern the deeper testing of the proposed model over more data from the Greek Information Society Framework Program in order to realise its behaviour. Moreover, further validation of the proposed method's applicability is considered, concerning the selection of ICT-based solutions in specific domains such as health, education and Government.

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