Applying the Fuzzy Analytical Hierarchy Process in Cognitive Cities

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ABSTRACT
This paper introduces a mobile application (app) as the first part of an interactive framework. The framework enhances the interaction between cities and their citizens, introducing the Fuzzy Analytical Hierarchy Process (FAHP) as a potential information acquisition method to improve existing citizen management endeavors for cognitive cities. Citizen management is enhanced by advanced visualization using Fuzzy Cognitive Maps (FCM). The presented app takes fuzziness into account in the constant interaction and continuous development of communication between cities or between certain of their entities (e.g., the tax authority) and their citizens. A transportation use case is implemented for didactical reasons.

Categories and Subject Descriptors
H.4.2 [Information Systems Applications]: Type of Systems – decision support

General Terms
Design, Human Factors, Management, Reliability, Theory.

Keywords

1. INTRODUCTION
The interaction of cities or of certain of their entities (e.g., transportation department) with their citizens changes constantly due to social conventions and technical innovations. Technology enables enhanced communication and alters its methods and goals to improve the interaction. The improvement and visualization (e.g., with a human-computer interface) of this interplay is the focus of existing research on cognitive cities (e.g., [12]). There already exists a vast amount of research on smart cities (e.g., [2], [7], [19]), although there does not exist a common denomination of smart and cognitive cities. The research topic is diverse and has numerous connecting factors. In 2011, Mostashari et al. used cognitive cities in a framework of intelligent urban governance by making single processes more cognitive. Previously, the term was mentioned in an architectural context (e.g., Cognitive Cities Conference (http://conference.cognitivecities.com), [16]). Along these lines, cognitive means that a city is able to learn, sense and adapt based on experiences and changes in the environment [12]. We understand smart cities as cities that use technology to constantly improve their interaction with their citizens. Now, cognitive cities are an extension of smart cities using cognition theory [12].

The goal of this research is to create an interactive app to improve the data acquisition and automation from a smart information system’s point of view, using the research outcome of Mostashari et al. as a basis [12]. For this purpose, we follow a design science approach [8]. Our app thereby combines Mostashari et al. [12] with FAHP and fuzzy research on the soft handling of big data (e.g., [14]).

Today, information is gaining ever greater value, and it multiplies itself continuously. Thus, everyone is confronted with big data. To offer the best possible decisions for their citizens, it is important for cities to filter out the right information from the growing data pool. Zadeh’s information granulation [24], for instance, proposes a way to address big data naturally [22]. An important aspect is information reduction [10], which helps to provide a better overview of all information, also important in human problem solving [21].

The Analytical Hierarchy Process (AHP) enables a hierarchical granulation [20]. It represents the hierarchical organization of given information. To address imprecision and uncertainty, fuzzy logic is added to conventional AHP. Then, FAHP makes it possible to work with uncertain information. This fuzzy hierarchical process facilitates the interactive decision-making process. Usually, no exact measurements are used in an interaction among multiple stakeholders, and therefore, applying fuzzy logic [23] is a way to address vagueness. Instead of searching for the best solution, it is often better to search for good enough (i.e., approximate) solutions that fit the needs [21]. Thus, the created app enables improved citizen management through FAHP. Applying this approach in E-Governance, the app enhances citizen management in a cognitive city. Currently, in Europe, there are several such ongoing E-Governance initiatives (e.g., [3]).

2. BACKGROUND
As presented, the term cognitive city was first used by Mostashari et al. [12] as an enhancement of smart cities. Key performance parameters must be defined for each stakeholder within the chosen context. Then, cognition allows the cities and their actors (i.e.,
stakeholders) to measure medium- and long-term impact on the performance metrics [12].

An intelligence amplification loop augments understanding by positive feedback learning between computers and humans [9], [13]. This augments not only human but also machine intelligence as they learn and adapt based on ongoing interaction [9], [13]. Emergence is a method that specifies this interactive learning. It can be seen as a way of growth (i.e., bottom-up) without a given plan or detailed prediction (e.g., [6]). Emergence is a key factor in our app because the app is intended for grassroots (i.e., basic) growth, as the interaction between cities and their citizens enhances understanding through continuous interaction.

Another key factor is Granular Computing (GrC). Because granulation is essential in human information processing and often simplifies the context of an issue [11], it offers a structured way to recognize, analyze, illustrate and solve problems [22]. Granules are subsets, groups, classes or clusters of elements assembled by indistinguishability, similarity or functionality [11], [20], [21], [26]. Granulation thereby corresponds to partitioning a case into a collection of granules [26]. The ability to conceptualize the current case at different granularities enables mapping the complexities of a situation in the easiest possible way [22]. One concept of GrC is hierarchy theory. In GrC, different entities of granularity are represented in a hierarchy, within which basic ingredients are levels. They consist of granules with distinguishing characteristics [22]. Hierarchy theory helps to understand, represent and conceptualize complex systems by distinguishing entities and their relationships among levels [22].

Saaty developed AHP, which is a multiple criteria decision-making tool [15], [17]. According to Saaty [15], a decision needs to be decomposed into four steps: first, problem definition; second, decision hierarchy building; third, construction of a set of pairwise comparison matrices; and last, use of priorities. Once the problem is defined, all relevant information about the case must be acquired. To build a hierarchy, the goal of the decision must be on the highest level. The subsequent levels are designed for the criteria on which subsequent elements depend. In a final step, on the lowest level, the set of alternatives is listed. Each element in an upper level is compared with an element in the level directly below. By applying this approach, qualification criteria can be prioritized through numbers [1]. Thus, to compare, a scale of absolute numbers (e.g., 1-9) is needed to express the relation between elements: 1 implies that both elements contribute equally to the goal, whereas 9 indicates evidence favoring one element over another. As a result, the higher the prioritization of an element, the more important it is. Through these comparisons, weighted priorities are obtained for every element. Now all possible alternative solutions can be evaluated and compared pairwise to select the solution with the overall highest total weighted priority value [1].

AHP is a tool with natural flexibility that enables its combination with different techniques [17]. Because judgments and preferences of a citizen are often subjective and not assignable to other citizens [15], AHP’s full capability is greatly increased through the use of fuzzy logic, which enables the modeling of vaguely defined statements [25].

Laarhoven and Pedrycz [18] present an extended fuzzy version of Saaty’s theory. They integrate fuzzy estimates into the prioritization of elements and measure the ability of each alternative to meet the decision criteria. Using this approach, they can even handle decision problems, where either no information or multiple sets of information are available for certain pairs of factors.

This type of approach plays a pivotal role in the human ability to make decisions in an environment of uncertain and imprecise perceptions (of citizens) [25]. The combination of AHP with fuzzy logic enables the handling of unsharp defined information [15], [18].

3. MOBILE APPLICATION

3.1 Introduction and Use Case

Mostashari et al. present a framework of interaction among data collection, stakeholders and infrastructure in a transportation case [12]. By combining emergence [6], GrC [21], [22], [26], FAHP [17], [18] and fuzzy stakeholder management [14], this framework will be enhanced, and as a first step, this combination will result in a new type of app. There already exist a multitude of different transportation apps (e.g., WAZE (www.waze.com), MTA App Quest (http://2013mtaappquest.challengepost.com)). However, our app enables enhanced E-Governance through intelligent and, most notably, adaptive information systems. The app combines existing technologies and processes the relevant data into an overall cognitive citizen management (i.e., E-Governance; section 4).

Here, we show a use case explaining the functionality of the app to enhance interaction in a cognitive city.

Daniel has an appointment for the evaluation of his tax report at the tax office on the other side of the city. He has checked the connections of the available transport facilities in advance using his cognition (from cognitive and city) app on his mobile phone. The app shows him the “best” way to the destination - based on several available transportation apps (e.g., MTA App Quest, WAZE). As he is leaving his apartment and heading for the elevator, the app advises him to take another route to the destination because of a traffic jam resulting from a fire. When he arrives at the bus station, he notices that the bus has a flat tire. At this exact second, the app tells him a new route because of the delay caused by the flat tire (i.e., the sensors in the tire informed the system of the rapid loss of pressure, and the system informed the transportation apps). Daniel must change from the bus to the train, and therefore, he can either walk or take a taxi to the train station. As he has for the most part used the most time efficient way to travel, he is advised to take a taxi (i.e., the app analyzed his travel history). Due to all these delays, the app recognizes that he will not be able to reach the destination in time for the appointment. Therefore, the app checks for other available taxi offices. Upon finding another available office, the app automatically requests an appointment and then informs Daniel of the new destination (by synchronizing the new destination with the transportation apps).

In the evening, after successfully evaluating his tax report, Daniel logs into the app and reviews its performance and his satisfaction rate regarding the endeavors of the day. He is able to manually input data for the review, but most of the data are generated by the app. This feedback helps him and the system to evolve and adjust future advice.

The meta-processing app used all available information (e.g., calendar, transportation apps, personal travel history), processed it in different granularities with the aid of FAHP and therefore calculated the fastest possible way to travel from his home to the desired destination (at the time of processing). Thanks to the app, citizens can react to incidents and thereby not only public transportation (e.g., bus) but the entire city traffic (e.g., cars) improves and E-Governance is enhanced.
3.2 Architecture
The app implements an automation of the constant interaction between cities and their actors. Fuzzy AHP is used as a basis to process the available information from the different sources. Figure 1 shows the framework and, as our current focus, the app. Below, we explain the data gathering in more depth, taking the use case as an example.

3.3 Harvesting Data
The app will improve the interaction between the citizens and stakeholder groups. The data for the app will be gathered through three different source types (Table 1): the users (e.g., personal information, preferences), the city systems (e.g., bus routes, traffic jams) and the Global Data Repository (GDR) (e.g., available information from apps, the Web, and Big Data).

Table 1: Data gathering of the mobile application.

<table>
<thead>
<tr>
<th>Method</th>
<th>Participation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Users</td>
<td>Active - Users will be able to actively feed data into the app through a manual input (e.g., feedback). These data will then be aggregated by the app.</td>
</tr>
<tr>
<td>Users</td>
<td>Passive - Users will be able to passively feed data into the app through their devices (e.g., smartphones, tablet computers, laptops) by enabling data interchange with the app on the devices (e.g., WAZE).</td>
</tr>
<tr>
<td>City systems</td>
<td>Location - The app will be able to gather data via the city systems (e.g., roads, buses, taxis, trains).</td>
</tr>
<tr>
<td>City systems</td>
<td>Internal input - The app will be able to gather data via internal input from city systems (e.g., administrators, announcements, internal stakeholders).</td>
</tr>
<tr>
<td>GDR</td>
<td>In addition to the above mentioned data gathering methods, data can be collected through GDR (e.g., available apps, the Web, Big Data).</td>
</tr>
</tbody>
</table>

3.4 Data Processing
Incoming data must be processed (e.g., in different granularity) to be useful for a cognitive city. The gathered data will be handled using FAHP. To optimize the citizens’ decision-making process, every involved field is classified into a granule. Therefore, one important granule (with all proper fields) is chosen, in which a decision becomes due because of an identified problem (AHP step 1; section 2). The app must build a hierarchy (step 2). On the top, there must be decision goals based on the corresponding field (e.g., travel from A to B). These goals require criteria (e.g., time) in the sublevels, and at the bottom, there are possible alternatives. The criteria and the alternatives are matrices, which must be compared with each other (step 3). Finally, each of these elements receives a priority in the form of an absolute number to state its importance (step 4). With fuzzy logic, algorithms can identify the appropriate value names of every element in the hierarchy and calculate an optimal solution (i.e., ad hoc) that is related to the defined priorities described in natural language. Thus, these algorithms, because they depend on the perceptions of citizens, are able to address imprecise (fuzzy) statements. This solution will be generally equal for all citizens, if there are no individual specifications. Specific users can enter their own criteria and weightings to create their own “optimal solution” for their individual needs. All the above mentioned data sources will then be processed according to the general or individual criteria, and an optimal solution for the current situation will be calculated until further information change the setting.

3.5 Benefit of the Mobile Application
Cognitive cities are complex systems, and therefore, there exists no single source of information, let alone one single optimal solution. Using fuzzy logic, our app takes this limitation into account and introduces a new way of processing available data in a cognitive city. GrC supports the app by gradienting given information into useful granules. FAHP enables improved processing of a multitude of available data according to specific needs. The hierarchical organization of information ensures understandable decision-making. By allowing uncertainty and imprecision, the app provides more realistic and real-time results. In other words, our app uses the available data (e.g., already available apps, user data, city systems data), processes the data (through GrC and FAHP) and delivers an optimal solution for the users.

Therefore, the app enhances E-Governance through the interaction between cities and their citizens by applying fuzzy logic. The benefit of our app is not only gathering and processing huge volumes of data in a short period of time (as existing apps do) but also aggregating the data and managing its natural fuzziness for improved (i.e., human-like) reasoning.

4. E-GOVERNANCE
Governance pertains to the way complex (i.e., socio-technical) systems are “governed”. Numerous actors are involved, none of which has sufficient power to govern the system on his or her own. Accordingly, governance is a matter of “co-ordination” among the actors (i.e., stakeholders) who can significantly affect the outcomes (i.e., the performance) of the system. E-Governance [4] applies the power of Information and Communication Technologies (ICTs) to such coordination. In doing so, these co-ordination mechanisms are somewhat altered, offering more opportunities for self-co-ordination (i.e., emergence) as well as for the app of market mechanisms [5].

In Mostashari et al.’s [12] definition of urban governance, the relevant stakeholders negotiate and adjust the collective set of processes by which consumption and service provision are dynamically (e.g., bottom-up) negotiated. The interests of the different stakeholders (i.e., citizens) are generally not aligned or ill-defined [12], such that the traditional recommendations of the government may not apply to everyone and individual solutions
are requested. With the input of the preferences (e.g., lowest price) and general interests (e.g., ecology) of each user (i.e., citizen) in the app, it is possible to circumvent this issue and to enhance the system for improved E-Governance. Even if only a marginal number of citizens use the active data input (e.g., to insert a traffic jam or the cause of it), the system and all citizens profit from the improved governance. This result is an enhancement of the reasoning of Mostashari et al. [12], which expressed a passive data input (i.e., location data) solution. However, the more people use the app, the better the app will become (e.g., WAZE).

5. CONCLUSION AND OUTLOOK
The presented app enables enhanced citizen management, mainly using GrC and FAHP, by gathering data and selecting the optimal transportation solution. Our use case shows the app’s functionality, and the subsequent section demonstrates the impact of the app on city traffic and thus E-Governance. With the app, public transportation of a city is improved, because traffic jams and accident sites can be avoided. A limitation of the app would be its restriction to bigger cities, which make a commitment to E-Governance, as the amount of required data and transportation choices for the app to work properly is rather high.

Our next research steps will be to further develop the app and the framework. We are currently at an early stage of development of both. The initial requirements are already available (e.g., [14]). We will work on the technical requirements and refine our algorithms to process the available data using GrC and FAHP.

6. REFERENCES