Enhancing Multidirectional Communication for Cognitive Cities

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***Abstract*—This paper presents the technical background and functionality of a meta-application (meta-app) for cognitive cities. The app enhances communication and thereby facilitates e-governance. This paper focuses on a user-centered implementation of the Fuzzy Analytical Hierarchy Process (FAHP) by presenting its technical specifications in relation with cognitive cities. For didactical reasons, a use case from the user perspective is included. Finally the findings are summed up and future work is presented.**

Keywords—Cognitive City; Decision-Making System; e-Governance; Fuzzy Set Theory; Fuzzy Analytical Hierarchy Process; Smart City

I. Introduction

The population of cities is growing constantly, as more people move to and live in cities every year (e.g., Global Health Observatory[1]). Simultaneously, technology is improving at a very high pace. As presented in [1], the interaction and communication between cities and their citizens is becoming ever more important. According to Boisson de Marca [2], interdependent systems within systems are serving as the lifeblood of global cities, determining their citizens' quality of life. In spite of various studies on smart cities (e.g., [3], [4], [5]) as well as previous research on cognitive cities (e.g., [6]), there is still no standard denomination of the terms "smart" and "cognitive" cities. Nevertheless, this study applies the perception of cognitive cities as introduced by Kaltenrieder et al. [1], which understands cognitive cities as a natural extension of smart cities, by introducing cognition theory [7] to its constant development. The very same approach could also be applied to the interaction between administrations, businesses and citizens in smart and cognitive cities (e.g., [8]) where cities can draw upon and support their citizens based on technology. This approach could further enhance the Knowledge Society Framework proposed by Meier [8] by equating cognitive cities with the knowledge society's top layer to build upon the three levels: *Information and Communication technology (ICT), Production and Participation* (Fig. 1). Another possibility is to implement the applied approach to citizen-to-citizen and business relations (c.f., sharing economy [9]).

Fig. 1: Cognitive Cities as part of the Knowledge Society.

The greater is the number of people who live in cities, the more a city and the everyday life of its citizens has to be improved (e.g., to foster and optimize coexistence). Applications already exist that enhance citizens' communication on a specific level (e.g., Waze[2]), initial applications also exist to connect different levels (e.g., Google Now[3]) and add an extra amount of reasoning power (e.g., Snips[4]). Yet, a more sophisticated application that combines these components to enhance communication and planning on a semi-automated level is still missing.

To this end, the proposed solution is a meta-app designed to enhance communication between all stakeholders (e.g., citizens, service provides, etc.) in a cognitive city by adding possible automated reasoning [10]. Instead of simply displaying alternatives and giving advice, the proposed meta-app (e.g., [1], [6], [11], [12]) aims to go the extra mile and act on behalf of its users (i.e., the citizens) if requested. Thus, this paper presents the technical environment of the meta-app as well as the proposed functionality and decision making in more detail. A design science approach [13] and Occam's razor (for its implication) (e.g., [14]) is followed.

II. Background

This section explains the theoretical background of the paper. The first subsection shows the shift from smart to cognitive cities, and the second explains the history of cognitive cities in more detail. The third introduces decision making with Analytical Hierarchy Process (AHP) and Fuzzy Analytical Hierarchy Process (FAHP). Different FAHP approaches and the subsequently chosen method for the paper are shown in the last subsection of the section.

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[1] http://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/
[2] http://www.waze.com/
[3] http://www.google.com/landing/now/
[4] http://snips.net/

A. From Smart to Cognitive Cities

Mostashari et al. [6] first used the term “cognitive city” in relation with smart cities and e-governance. Kaltenrieder et al. [1] further developed the term by including cognition theory. They separated “cognitive” from “smart” cities by including not only citizen-to-citizen but also citizen-to-computer system interaction in relation with smart cities.

Cognition theory, or more specifically connectivism, was introduced by Siemens [7]. It is understood to be constant learning, while nurturing connections. Under this perspective, learning is not restricted to humans, but can be interconnected between various knowledge carriers. The ability to access accurate and up to date knowledge from other (human) knowledge carriers when it is needed is an essential part of the theory. This means that acquiring and maintaining knowledge is expanded from personal to multi-agent dimensions (e.g., human to human, human to computer system, computer system to computer system).

B. History of Cognitive Cities

To conceive of cognitive cities, it is important to see that in a city, all citizens and their interactions (e.g., with other citizens as well as computer systems) are the center of attention. However, human perception is often full of uncertainty and imprecise or partial knowledge. Fuzzy logic is a possibility to deal with this imprecision, since it allows handling of partial knowledge [15].

Unlike a classical set, a fuzzy set is not defined through its contained elements; rather, every element is contained in every fuzzy set, but only to a certain degree (which can be zero). This degree of membership to a fuzzy set *A* (and thus the fuzzy set itself), is determined by its membership function $f_A(x)$, which maps an arbitrary element x to the real interval [0,1]. In this paper triangular fuzzy numbers are used, since they help enhancing decision making [16]. A triangular fuzzy number $\tilde{a}$ can be represented as $\tilde{a} = (l, m, u)$ where l, m and u are real numbers. These real numbers stand for the lower (l) and upper (u) limit of the support of $f_{\tilde{a}}(x)$ and for the most likely point m, (i.e., where $f_{\tilde{a}}(m) = 1$). Thus, the membership function is

$$f_{\tilde{a}}(x) = \begin{cases} (x-l)/(m-l), & for\ l \le x \le m \\ (u-x)/(u-m), & for\ m \le x \le u \\ 0, & else. \end{cases} \qquad (1)$$

The reciprocal of a fuzzy number $\tilde{a} = (l, m, u)$ is denoted as $1/\tilde{a} = (1/u, 1/m, 1/l)$ [16]. It is easy to see that a crisp number can be expressed as the fuzzy triangular number $\tilde{n} = (n, n, n)$, with $f_{\tilde{n}}(x) = 1$ if $x = n$ and 0 elsewhere [28]. Fuzzy logic can also be used to handle linguistic terms as fuzzy numbers [17]. For instance, following Sarfaraz et al. [16] comparisons such as “equally important,” “essentially important” or “absolutely important” can be interpreted as the fuzzy numbers $\tilde{a}^{ei} = (1,1,1)$, $\tilde{a}^{essi} = (4,5,6)$ and $\tilde{a}^{ai} = (7,8,9)$ providing a fuzzy linguistic scale to establish the fuzzy comparison matrices.

C. Decision-Making in Cognitive Cities

To enable the development of a meta-app, it is essential to introduce a possible decision-making concept for cognitive cities. AHP was developed by Saaty to facilitate multiple criteria decision-making [11], [18]. Following Saaty [11] the four steps consist of problem definition, decision hierarchy building, construction of comparison matrices and lastly the use of priorities. When the problem is understood and all relevant information is gathered, a hierarchy can be built. Therefore, the goal of the decision on the highest level is followed by the criteria on the subsequent levels. These criteria are used to evaluate the lower level elements (i.e., with respect to their importance regarding the criterion directly above). On the bottom level, the alternatives of the decision are listed. Now, as in [19] a pairwise comparison matrix is established by assessing a number $m_{x,y}$ from 1 to 9 (or their reciprocal) to every relation of elements *x* and *y*, determining the dominance of the element *x* over *y*, regarding its influence on the superior criterion. Thereby, 1 indicates that *x* has the same influence on the criterion as *y*, while 9 means *x* has the highest possible advantage over *y*. This relationship is obviously not symmetric, because the inverse is incorrect for all assessed numbers other than 1. Instead $m_{y,x}$ is equal to the reciprocal value of $m_{x,y}$, (i.e., $m_{x,y} = 1/m_{y,x}$). Such pairwise comparison matrices are made for every pair of elements under the same criterion, on every level. One way to obtain the local priority vectors (i.e. corresponding to one criterion) from the comparison matrix is to normalize the matrix (e.g., $m_{x,y}^{norm} = m_{x,y}/(\sum_i m_{i,y})$) and take the mean over the row. The global best alternative is the one with the highest value, obtained through weighting the sum of the local priorities of the alternatives with the respective priority of the superior criterion [19]. Superimposing fuzzy logic increases AHP’s capability, by enabling vaguely defined statements modelling [1].

Building upon Saaty’s AHP [11], FAHP was originally described by Van Laarhoven and Pedrycz [20]. Since then, various approaches have been presented (e.g., [21]; subsection II.D). Following Wang and Chin [22] for instance, they can be separated into two categories, both based on fuzzy judgments (i.e., fuzzy numbers) in the comparison matrix of classical AHP. One category derives fuzzy weights from the fuzzy comparison matrix, and the other from crisp ones. According to Mandic et al. [23] and Wang and Chin [22], the most frequently used approach is that of Chang [24], which belongs to the second category. Through fuzzy numbers, comparisons can be made approximately or based on unsharply defined information [11], [20]. Therefore, FAHP can handle decision problems in an environment of uncertain and imprecise perception [17].

D. Review of similar FAHP approaches

As already mentioned in the previous subsection, there is a multitude of approaches to combine fuzzy set theory with AHP. In category one, Van Laarhoven and Pedrycz [20] used triangular fuzzy numbers in their comparison matrix and a fuzzy logarithmic least-squares methods to derive fuzzy scores for the alternatives. Buckley [21] also proposed a method to derive fuzzy scores, but with a geometric mean approach to derive the fuzzy weights from fuzzy comparison ratios. Later, Csutora and Buckley [25] worked on a fuzzy extension of the lambda-max approach of Saaty's AHP, using triangular and trapezoidal fuzzy numbers and Wang developed a linear goal programming model to derive normalized fuzzy weights [26]. As already stated, Chang [24] introduced today's most used approach. His method to use an extended analysis to derive crisp priorities from triangular fuzzy comparison matrices belongs to the second category. Mikhailov [27] also derived crisp priorities from fuzzy comparison matrices by transforming the prioritization-problem into a fuzzy linear program. This method is called fuzzy preference programming.

In this paper, the approach to a fuzzy multicriteria decision model of Opricovic and Tzeng [28] is used. Since the meta-app uses many different sources to gather data, fuzzy information cannot be excluded. Similar to the above presented approaches, fuzzy judgments are allowed in the comparison matrix in the form of triangular fuzzy numbers. Following Opricovic and Tzeng [28], these fuzzy comparison matrices are defuzzified (i.e., fuzzy triangular entries of the matrix are mapped to crisp real numbers) before using the classical AHP to derive the best alternative. This way, fuzzy judgments and fuzzy data can be handled. Given a triangular fuzzy number matrix $(\tilde{a}_{ij})$ (e.g., TABLE I. in subsection IV.A), the defuzzification process of $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ is as follows [28]:

1. Step: Normalization of the matrix
   a) Define

$$u_i^{max} = \max_j u_{ij} \quad (2)$$

$$l_i^{min} = \min_j l_{ij} \quad (3)$$

$$\Delta_{min}^{max} = u_i^{max} - l_i^{min} \quad (4)$$

   b) Then, compute

$$x_{lj} = (l_{ij} - l_i^{min}) / \Delta_{min}^{max} \quad (5)$$

$$x_{mj} = (m_{ij} - l_i^{min}) / \Delta_{min}^{max} \quad (6)$$

$$x_{uj} = (u_{ij} - l_i^{min}) / \Delta_{min}^{max} \quad (7)$$

2. Step: Computation of left (*l*) and right (*u*) normalized values

$$x_j^l = x_{mj} / (1 + x_{mj} - x_{lj}) \quad (8)$$

$$x_j^u = x_{uj} / (1 + x_{uj} - x_{mj}) \quad (9)$$

3. Step: Computation of total normalized crisp value

$$x_j^{total} = \left[x_j^l\left(1 - x_j^l\right) + x_j^u x_j^u\right] / (1 + x_j^u - x_j^l) \quad (10)$$

4. Step: Compute final crisp value

$$a_{ij} = l_i^{min} + x_j^{total} \Delta_{min}^{max} \quad (11)$$

Applying this method to the matrix $(\tilde{a}_{ij})$ converts every fuzzy $\tilde{a}_{ij}$ into a crisp a_{ij} resulting in a crisp matrix (a_{ij}), which can be used to derive the priorities in the AHP. As Opricovic and Tzeng [28] stated, this defuzzification-method can be applied for mixed sets of crisp and fuzzy numbers. Furthermore this method distinguishes between two symmetrical (i.e. $m - l = u - m$) fuzzy numbers with the same mean, displaying an advantage over the more commonly used centroid method [28].

III. Proposed Vision of Cognitive Cities

In this section, the capabilities and functionalities of FAHP for cognitive cities are explained, enhancing multidirectional communication in cognitive cities. Subsection A shows the architecture of the meta-app and the subsequent subsections explain the different building blocks. Finally, demonstrating a possible implementation of the meta-app, subsection F illustrates the building blocks' interaction.

A. Architecture of the Meta-App

The architecture of the meta-app is illustrated in Fig. 2. The architecture shows the interaction between its four building blocks: *Meta-App*, *History*, *Processing* and *Acquisition*. All building blocks simultaneously work for themselves and interact with each other. FAHP serves as the interface between the blocks and is influenced by them.

The building blocks each include an activity (e.g., *acquisition of available data*) as well as dataflow. These dataflows can either be from outside (e.g., the Web) or inside the meta-app (i.e., between building blocks.) The activities are processing information for the building blocks as well as for the entire meta-app.

B. Acquisition

The global data repository is the data basis of the architecture. Data acquisition and conditioning is the main activity of this building block. The data is stored through fuzzy cognitive maps using the WebKnowARR framework and graph databases [12]. Instead of reinventing and rebuilding the functionalities of existing apps, the meta-app provides an Application Programming Interface (API) for data input that enables third party providers to design apps to improve and enhance the meta-app. Data input from existing apps is also enabled through the API, providing needed information for the meta-app (e.g., transportation data from Waze). In this way, tested and functioning data transfer is used to empower the meta-app. In addition, data from the Web is acquired and conditioned to add to the meta-app. The Web data is used to complete the user profile and to improve the decision-making of the FAHP.

C. History

The meta-app history serves as the memory of the meta-app. Its main purpose is to store all processed and prioritized information. Thereby, the FAHP is constantly able to store current processes and decisions (e.g., Fig. 3; TABLE I.) as well as match them with previous processes and decisions. The meta-app history is constantly synchronizing all available data from the meta-app.

D. Meta-App

The meta-app acts as a contact point to the user, giving and receiving information to and from the user through a Graphical User Interface (GUI). In addition, data is acquired by the meta-app through the sensors of the user's mobile device, feeding it together with the information from the GUI to the FAHP and to all other building blocks.

E. Processing

The FAHP uses all available information from the other building blocks to calculate the most suitable alternatives for the user. Constant calculation and re-evaluation of the chosen FAHP approach, including the four defuzzification steps (subsection II.D) and the subsequent four steps of the classical AHP (subsection II.C) are taking place. The next subsection explains the chosen FAHP approach in more detail.

F. Interaction of the Building Blocks

As demonstrated in Fig. 2, all building blocks are constantly interacting with each other as well as with outside data and information providers through APIs and the GUI. When new data is brought in from an existing app through an API, it is processed and conditioned in the global data repository. The new information is matched against information from the Web and from third party providers, then made available to the FAHP. The FAHP then processes this new information and feeds it into the meta-app history to synchronize it with existing historic data. As soon as the information is synchronized, it is fed back to the FAHP where it is processed. Thanks to the processing power of the meta-app, this interaction should be completed in a very short timeframe (i.e., unperceived by the user). If the updated information changes something in the decision-making and another alternative is chosen, then this new alternative is processed by the meta-app and presented to the user via the GUI.

IV. FAHP DECISION-MAKING IN COGNITIVE CITIES

In this section, the information processing and decision making process of the FAHP for cognitive cities is shown in the first subsection, and a use case showing a possible use of the meta-app is presented in the second. The third presents a critical assessment of the meta-app.

A. Decision-Making

The meta-app is able to process information and make decisions by itself. The user has to agree (i.e., through the GUI) that the meta-app can use their GPS coordinates and can access all data available for and by the user to reach its full potential. The FAHP serves as the decision-making body for the meta-app by constantly calculating the most suitable alternatives.

The meta-app constantly checks the calendar of the user and recognizes their existing appointments. As soon as an appointment is due in the near future, the meta-app uses all available information to calculate the most suitable way for the user to reach the appointment. Fig. 3a shows the highest priority level of the meta-app. There the FAHP starts its calculation, with the highest priority being to reach the appointment. Thus, the transportation must be feasible. The (fuzzy) information for the sublevels of the transportation decision is provided by the global data repository building block and the meta-app history building block. As soon as the most suitable alternative is calculated, by first transforming the fuzzy matrices into crisp ones as in subsection II.D and then applying AHP, it is presented to the user through the display of the meta-app. Fig. 3b shows the transportation information (accessed through a transportation app) to reach the appointment, with the priorities derived from the matrices of all criteria, which are analogical to TABLE I.

TABLE I. FAHP MATRIX

Time	**Transportation mean**			
	Train	***Bus***	***Taxi***	***Walk***
Train	(1,1,1)	(2,3,4)	(1/7,1/6,1/5)	(5,6,7)
Bus	(1/4,1/3,1/2)	(1,1,1)	(1/8,1/7,1/6)	(4,5,6)
Taxi	(5,6,7)	(6,7,8)	(1,1,1)	(7,8,9)
Walk	(1/7,1/6,1/5)	(1/6,1/5,1/4)	(1/9,1/8,1/7)	(1,1,1)

This alternative is constantly checked through the process shown in Fig. 3a. If something unexpected happens and there is any delay that prevents the use of the former most suitable choice, the process of Fig. 3b begins once again, as the transportation has to be adapted. For instance, due to the delay, the priority of transportation time rises, (e.g., from 0.48 to 0.8). The newly calculated result of transportation is then checked by the process of Fig. 3a. If the outcome of the process is *ok*, then the new alternative is presented to the user and the constant checking of the chosen alternative starts again. In the case that the appointment can no longer be reached in time (i.e., given all

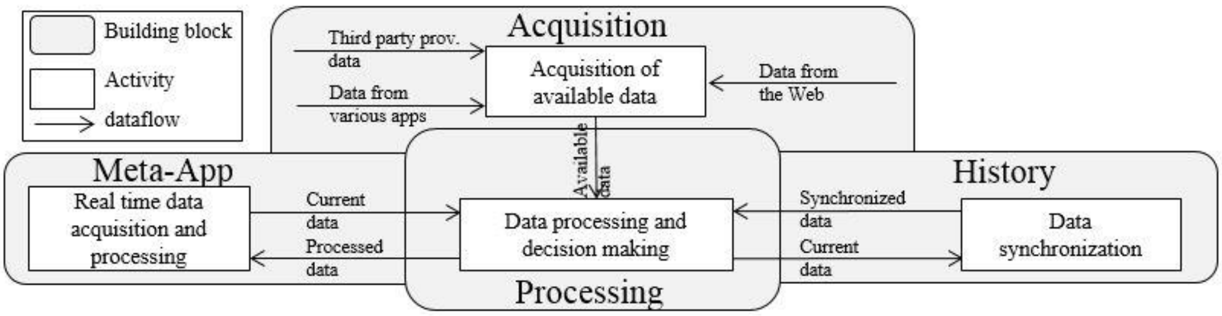

Fig. 2 Architecture of the meta-app.

possible changes of transportation) the process shown in Fig. 3a starts the process shown in Fig. 3c. The appointment must either be changed or cancelled. The meta-app can change the appointment automatically (if this feature is enabled by the user) or else inform the user about the required change of the appointment. If the automatic change of appointments is disabled, then the meta-app provides the user with the most suitable appointment (the process is similar to the process shown in Fig. 3a), and the user only has to click *yes* to change the appointment or *no* to leave it untouched. A denied manual change of the appointment results in the choice of another possible appointment or the cancellation of the appointment. If the appointment is cancelled, all the provided transportation means and times will be no longer be visible.

B. *Use Case from the User Perspective*

This subsection shows a use case explaining the functionality of the meta-app from a user's perspective.

Today The fourth anniversary of his company and the celebratory party is not keeping James from busy meetings with clients. All four of his employees are also working to ensure more years of profitable existence for the company. James has booked a nice table in a cozy little Japanese restaurant to celebrate the anniversary properly.

5:00 PM The table is booked for 7:00 PM, meaning that the dinner is only two hours away, but James is still in a meeting. His smartphone is vibrating, telling James that he should take the train in 30 minutes to arrive at the restaurant in time (i.e., Fig. 3a).

5:30 PM Time is passing and the meeting is continuing. The meta-app is constantly recalculating the possible routes and means to be able to reach the dinner at seven.

6:00 PM The client meeting is complete and therefore the meta-app tells James that a taxi will be his only mean of transport to reach the restaurant.

The meta-app is not only checking James' location and, but also those of all his employees, as they are also using it (i.e., processing all available information, Fig. 2). The meta-app calculates that Deborah will not be able to join the dinner at the scheduled time. Therefore, it books a table in another Japanese restaurant (i.e., performing an automated appointment change, Fig. 3c) where James has already eaten and given a high ranking on their website (i.e., processing all available information, Fig. 2). This new restaurant has a table open at 7.00 PM and is reachable for all five people (i.e., according to their GPS position). The calculation also notes that none of these five users is already on their way to the former location.

As all of these calculations are done by the meta-app in a very short time, James gets the notification that the restaurant has changed and that all five people are on their way to the new restaurant. The four employees receive a similar notification telling them their new destination.

7:00 PM All five people have arrived at the Japanese restaurant.

11:00 PM As James arrives at home later after the celebration, he is still happy having his new meta-app working as his powerful electronic assistant. This assistant has as much competence as James has allowed, giving its history and settings.

C. *Critical Assessment of the Meta-App*

The biggest benefits of the meta-app lies in the chosen FAHP approach, as it enables constant calculation of the most suitable alternatives for the user. By doing this, the meta-app not only considers the information and the alternatives for a single user, but also takes into account the available data (anonymously) of all users using the meta-app. Therefore, this information enables the meta-app to calculate the most suitable alternatives for all users, constantly cross-referencing them (anonymously) to other users and thereby improving dataflow as well as the transportation systems of the cognitive city. This is especially useful if certain users are connected (e.g., work together) and have common appointments and goals. In this case the data flow is not anonymous.

Another benefit is the automated rescheduling of unreachable appointments for users (if desired). Reducing unattended appointments enhances efficiency and creates space for other users to book the newly free appointments and thereby saves time. Further benefits are enabled when third party providers generate data for the meta-app. New apps can be interconnected with existing apps through APIs, which allows the meta-app to create both economic opportunities and user benefits in a cognitive city [29]. The more apps the meta-app is able to connect to and access, the greater the benefit for the users of the meta-app, because the available data is more diverse and the output is more specific. All these benefits also enhance multidirectional communication as they optimize and enhance the interaction between users, systems and institutions.

The possible loss of self-responsibility due to automated reasoning is one disadvantage of the meta-app. Users could blindly follow the instructions of the meta-app, thereby reducing their personal responsibility to scrutinize decisions.

Another challenge is the possible shortage of available data. The functionality of the meta-app would be reduced if the meta-app could not access existing applications, as they would prohibit the use of their data.

A further challenge is the protection of citizen's privacy. It is necessary that users of the meta-app allow processing all available information connecting different heterogeneous

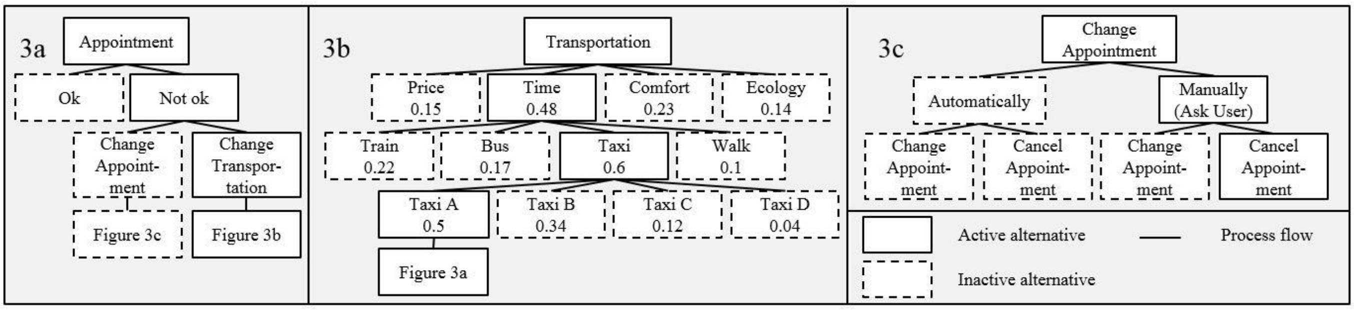

Fig. 3: Decision making with the FAHP.

networks and systems to receive the best possible alternative for a decision-making [30]. As it is a perfect target for attacks willing to disclose sensitive information from citizens, it is crucial to ensure the achievement of privacy within the meta-app to guarantee the fundamental right of them at all times [30]. According to [31], there are 7 foundations principles to ensure privacy and gain personal control over one's information (c.f., [31]). There is still a lot to do for the privacy issue and thus, important to develop techniques to enhance citizen's privacy.

V. CONCLUSION AND OUTLOOK

This paper further enhances the idea of a mobile application and presents the underlying functionality of the chosen FAHP approach as well as the entire meta-app in detail. The presented meta-app enhances multidirectional communication for cognitive cities by combining existing mobile apps. Thereby, picking the available state of the art functionalities and combining them to empower users and to facilitate cognitive cities. As a methodological background for the meta-app, FAHP enables decision-making based on existing uncertain knowledge, resulting in the most suitable alternatives for its users. This meta-app enhances the coexistence and cognition of a city. A limitation would be that the city, the application providers and the users all must be convinced that data privacy requirements are adhered to, as the meta-app can only reach its full capabilities with access to (open) data and information.

The next research step will be to further develop the meta-app by designing the requirements for information storage in detail (e.g., defining the underlying graph database (e.g., Neo4j[5])). Additionally, the algorithms to process the information (FAHP) will be compared and specified. A further step in research will be to develop a prototype based on the detailed requirements. To support the proposal of the meta-app a detailed study will be done to practically evaluate the application. An important future research step will be to emphasize the importance of the privacy issue and to do further research to enhance the protection of privacy.

REFERENCES

[1] P. Kaltenrieder, E. Portmann, S. D'Onofrio, and M. Finger, "Applying the Fuzzy Analytical Hierarchy Process in Cognitive Cities," Accepted for the 8th International Conference on Theory and Practice of Electronic Governance (ICEGOV), 2014.

[2] J. R. Boisson de Marca, "Smarter Cities… and Wiser Ones?", In IEEE-The Institute 38(2), p. 13, 2014.

[3] A. Caragliu, C. Del Bo, and P. Nijkamp, "Smart cities in Europe," (No. 0048), 2009.

[4] R. Hollands, "Will the real smart city please stand up?," City, 12(3), 2009, pp. 303-320.

[5] D. Washburn and U. Sindhu, "Helping CIOs understand "Smart City" initiatives," Growth, 2009.

[6] A. Mostashari, F. Arnold, M. Mansouri, and M. Finger, "Cognitive Cities and intelligent urban governance," Network Industries Quarterly, 13(3), 2011.

[7] G. Siemens, "Connectivism: A learning theory for the digital age," in International journal of instructional technology and distance learning 2(1), 2005, pp. 3-10.

[8] A. Meier, "EDemocracy & EGovernment: Stages of a democratic knowledge society," Springer, 2012.

[9] J. Rifkin, "The zero marginal cost society: The Internet of things, the collaborative commons, and the eclipse of capitalism," Macmillan, 2014.

[10] E. Portmann, A. Thiessen, "Web 3.0 Monitoring im Stakeholder Management," in HMD Praxis der Wirtschaftsinformatik, *50*(5), 2013, pp. 22-33.

[11] T. L. Saaty, "Decision making with the analytic hierarchy process," in International Journal of Services Sciences, 2008, pp. 83-95.

[12] E. Portmann and P. Kaltenrieder, "The Web KnowARR Framework: Orchestrating computational intelligence with graph databases," in Information Granularity, Big Data, and Computational Intelligence, W. Pedrycz and S.M. Chen, Eds. Springer Verlag, Berlin Heidelberg, 2015, pp. 325-346.

[13] P. Johannesson and E. Perjons, "A design science primer," CreateSpace, 2012.

[14] E. Portmann, "A fuzzy grassroots ontology for improving social semantic web search," Proceedings of 6th international summer school on aggregation operators, Benevento, 2011.

[15] L. A Zadeh, "Fuzzy sets," in Information and Control 8(3), 1965, pp. 338-353.

[16] A. Sarfaraz, K. Jenab and A. C. D'Souza, "Evaluating ERP implementation choices on the basis of customisation using fuzzy AHP," in International Journal of Production Research, 50(23), 2012, pp. 7057-7067.

[17] L. A. Zadeh, "Fuzzy logic," Computer, 21(4), 1988, pp. 83-93.

[18] O. S. Vaidya and S. Kumar, "Analytic hierarchy process: An overview of applications," in European Journal of Operational Research 169, 2006, pp. 1-29.

[19] K. M. Al-Subhi Al-Harbi, "Application of the AHP in project management," in International Journal of Project Management, 19, 2001, pp. 19-27.

[20] P. J. M. Van Laarhoven and W. Pedrycz, "A fuzzy extension of Saaty's priority theory," in Fuzzy Sets and Systems, (11), 1983, pp. 229–241.

[21] J. J. Buckley, "Fuzzy hierarchical analysis," in Fuzzy sets and systems, 17(3), 1985, pp. 233-247.

[22] Y. M. Wang and K.S. Chin, "Fuzzy analytic hierarchy process: A logarithmic fuzzy preference programming methodology," in International Journal of Approximate Reasoning, 52(4), 2011, pp. 541-553.

[23] K. Mandic, B. Delibasic, S. Knezevic, and S. Benkovic, "Analysis of the financial parameters of Serbian banks through the application of the fuzzy AHP and TOPSIS methods," in Economic Modelling, 43, 2014, pp. 30-37.

[24] D. Y. Chang, "Applications of the extent analysis method on fuzzy AHP," in European journal of operational research, 95(3), 1996, pp. 649-655.

[25] R. Csutora and J. J. Buckley, "Fuzzy hierarchical analysis: the Lambda-Max method," in Fuzzy Sets and Systems, 120(2), 2001, pp. 181-195.

[26] Y. M. Wang and K.S. Chin, "A linear goal programming priority method for fuzzy analytic hierarchy process and its applications in new product screening," in International Journal of Approximate Reasoning, 49(2), 2008, pp. 451-465.

[27] L. Mikhailov, "Deriving priorities from fuzzy pairwise comparison judgements," in Fuzzy Sets and Systems, 134(3), 2003, pp. 365-385.

[28] S. Opricovic and G. H. Tzeng. "Defuzzification within a multicriteria decision model," International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, 11(05), 2003, pp. 635-652.

[29] G. Anthes, "Invasion of the mobile apps," in Communications of the ACM, 54(9), 2011, pp. 16-18.

[30] A. Martinez-Balleste, P.A. Pérez-Martínez, and A. Solanas, "The pursuit of citizens' privacy: a privacy-aware smart city is possible," Communications Magazine, IEEE, 51(6), 2013, pp. 136-141.

[31] A. Cavoukian, "Privacy by design: The 7 foundational principles," Information and Privacy Commissioner of Ontario, 2009, Canada.

[5] http://www.neo4j.org/