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Decision-Making Support System for Quality Smart City Services

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Abstract — This paper presents the results of research carried out in the field of developing decision support systems for quality Smart City services. The decision-making system consists of two sets of Agents: Service Provider Agents and Service Consumer Agents. The interaction between the Agent sets is governed by the knowledge base which is managed by the Service Quality Assessors. Service quality is evaluated based on a Multi-Objective Optimization model competitively performed by applying game theory (Nash Equilibrium) between Agent sets involving available resources and knowledge. The paper developed: interaction diagram between Agents and services offered by Smart City, interaction diagram between sets of Agents to provide quality services, and multi-level infrastructure diagram for decision support system. The Multi-Objective Optimization problem is defined in the form of the set of objective functions for the evaluation of service quality and the set of constraint functions for service state parameters and action parameters for service provision.

Keywords—Smart City; Decision Making; Multi-Agent System; Artificial Intelligence; Knowledge; Multi-Objective Optimal Solution; Service Quality; Game Theory; Nash Equilibrium.

I. INTRODUCTION

The process of urbanization, which has become increasingly intense in recent years, also imposes certain quality criteria on the infrastructure and services offered by economic agents, management and monitoring services. From the criteria that determine the quality of life, the most important services can be identified, the integrity of which lies at the basis of a smart city: industrial and production services, public transport services, logistics services, marketing services, medical services, water and sewage services, environmental services, educational services, electricity and gas services, public services, information and legal services, etc. All of these can be interpreted as independent of each other, but also in collaboration, which presents a symbiosis of services that determine the quality of life offered by the urban environment. According to data presented on the Internet, the 10 most recognized smart cities in the world are Singapore, Dubai, Oslo, Copenhagen, Boston, Amsterdam, New York, London, Barcelona and Hong Kong. The quality of services offered by Smart City depends on the technological complexity of the resources involved and the models applied in their functionality [1-3].

A Smart City is defined as an entity that exploits information and communication technologies [4, 5] to improve the quality of life of its citizens by providing them with improved services while ensuring efficient use of the limited resources available. In the works [2, 3] smart city is defined as a system of service delivery and consumption. To improve the quality of services and optimize the consumption of resources, information provided by economic agents, businesses and inhabitants is used and subjected to an inference process thus providing decision makers with a comprehensive operational picture.

From a conceptual point of view, the most effective can be considered the decision models provided by Multi-Agent Systems [6] whose functionality is based on Artificial Intelligence [7], which solves the Multi-Objective Optimization problem [8, 9] in an N-dimensional space.

Application-oriented Multi-Agent decision systems for Smart City applications present a distributed computing architecture that integrates the latest methods and technologies [4, 5], for structural organization and data transfer, and the latest techniques for data acquisition, processing and storage [10-13].

The objective of the research carried out in this paper is to develop a Multi-Agent System for decision support in order to ensure the quality of services provided by Smart City. The specified objective is achieved through the application of a service quality assessment model based on Multi-Objective Optimization and Game Theory (Nash Equilibrium).

II. Statement of the Research Problem

The Smart City is defined $SC=\left\{S, A^{SP}, A^{SC}, Q\right\}$, where: $S=\left\{s_m, \forall m=\overline{1,M}\right\}$ is the set of services offered by the Service Providing Agents (SPA) set and consumed by the Service Consuming Agents (SCA) set, $S\in R^N$, R^N is considered as the activity environment and $s_m \subseteq R^N, m=\overline{1,M}$, where each service $s_m=\left\{X^{S_m}, Y^{S_m}, Q^{S_m}\right\}$, is characterized by: $X^{S_m}=\left\{x_n^{S_m}, \forall n=\overline{1,N^{S_m}}\right\}$ - the set of variables for identifying the state of the service s_m, $Y^{S_m}=\left\{y_n^{S_m}, \forall n=\overline{1,N^{S_m}}\right\}$ - the set of variables for acting on the service s_m, Q^{S_m} - the set of parameters for evaluating the quality of the service s_m; $A^{SP}=\left\{A_i^{SP}, \forall i=\overline{1,I}\right\}$ is the set of Service Providing Agents; $A^{SC}=\left\{A_j^{SC}, \forall j=\overline{1,J}\right\}$ is the set of Service Consuming Agents; $Q=\left(\bigcup_{i=1}^{I}(q_i)\right)\cap\left(\bigcup_{j=1}^{J}(q_j)\right)$ is the quality of the services offered by the SPA set and consumed by the SCA set and $Q^{S_m}\subseteq Q$. Under real economic activity conditions the following statement is admissible: $A^{SP}\bigcap A^{SC}=\varnothing$.

The interaction between SPA, Services offered by Smart City and SCA is shown in Figure 1.

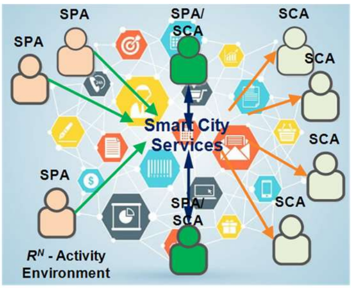

Fig. 1. Interaction between Agents and Services offered by Smart City.

The Agents' activity is carried out in the activity space R^N where the set of SPA Agents through Y^{S_m} act on the services offered by Smart City ensuring their quality and quantity. The set of SCA Agents perceive the state of the services through X^{S_m} evaluating its quality Q^{S_m}. If the quality of the service Q^{S_m} is satisfactory, it is consumed.

III. Logical Interaction of Agents

As specified the objectives of the decision support system is the provision of quality services by the Smart City. At the basis of the functionality of the decision support system is the multitude of Agents operating on the basis of knowledge-based models that are cumulative in nature and develop during the course of the system's activity. Figure 2 shows the logical interaction diagram between Agents for the use and accumulation of new knowledge that will ensure quality services provided by the Smart City.

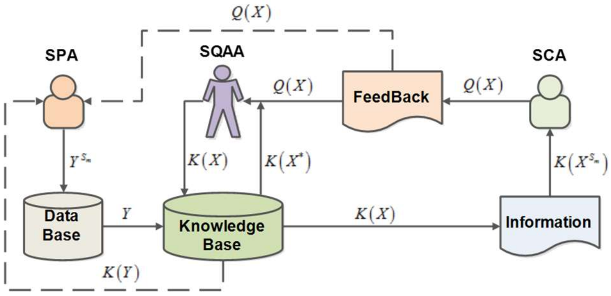

Fig. 2. The logical interaction of Agents for qualitative Smart City Services.

The Agent interaction diagram (Figure 2) includes the multitude of Service Provider Agents (SPAs) that generate the set of service action variables Y^{S_m} . The values of these variables are stored in the ***Data Base*** for a long period of time forming the set of variables $Y = \bigcup_{m=1}^{M} \left(Y^{S_m} \right)$ that are used to generate new knowledge stored in the ***Knowledge Base***. For decision making the SPA set applies the knowledge $K(Y)$ from the ***Knowledge Base*** and the feedback $Q(X)$ generated by the SCA set. In turn the SCA set for decision making applies the knowledge $K(X)$ from the ***Knowledge Base*** that is specified in the description information $K\left(X^{S_m}\right)$ of the respective service. As a result of service consumption S_m the SCA set generates the ***Feedback*** reaction $Q(X)$ which is used by the SPA and SQAA set. The Service Quality Assessment Agents (SQAA) set presents a superior oversight body for service quality assessment standards. They analyze the opinion $Q(X)$ generated by the SCA set and the current state of the ***Knowledge Base*** $K\left(X^*\right)$ as a result of which they generate new knowledge when needed, $K(X)$, which is stored in the ***Knowledge Base*** and then used by the Agents in the business process.

IV. SYNTHESIS OF MULTI-LEVEL INFRASTRUCTURE MODEL

Decision-Making Support System for Quality Smart City Services presents a complex framework that integrates a multitude of techniques and technologies into a single functional system. In order to efficiently structure the techniques and technologies used it is proposed to summarize the multi-level infrastructure model shown in Figure 3.

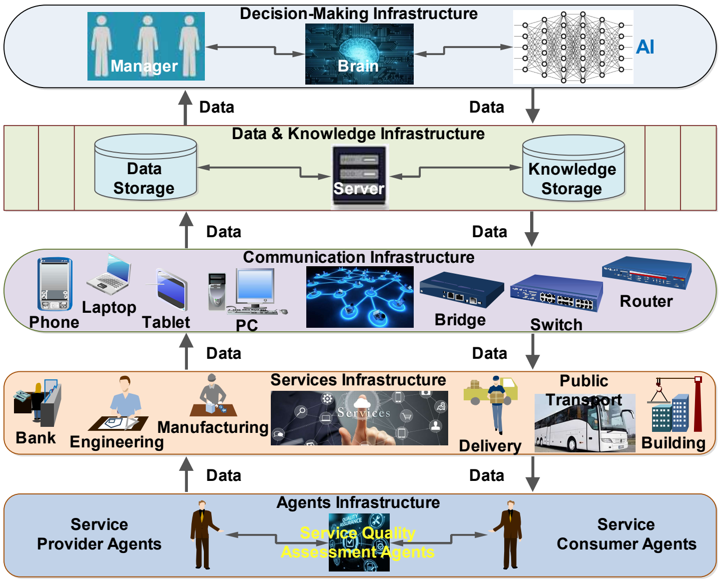

Fig. 3. The multi-level infrastructure model for Decision-Making Support System.

The multi-level infrastructure model for the Decision Support System is structured on 5 levels: ***Agents Infrastructure; Services Infrastructure; Communication Infrastructure; Data & Knowledge Infrastructure; Decision-Making Infrastructure.*** Communication between the levels takes place in the form of data structures or blocks..

Agents Infrastructure. Integrates the multitude of Agents (SPA, SCA, and SQAA) that present individuals or companies, software products or embedded devices. Agent status is defined by their functional and artificial intelligence capabilities [6, 14, and 19].

Services Infrastructure. It integrates all economic, financial, industrial, manufacturing, transport, construction, etc. entities that are integrated into the Smart City architecture [1, 2, 3, and 16].

Communication Infrastructure. Communication infrastructure is one of the fundamental elements of a Smart City. They are oriented towards organizing the exchange of data and information between users and data processing systems (Phone, Laptop, Tablet, PC), and the exchange of data between electronic devices that form communication network topologies and provide data transfer (Bridge, Switch, Router) using communication protocols. An example of smart city organization is the use of IoT technology that offers the whole range of protocols (MQTT, CoAP, HTTP, DDS, ZigBee, LoRaWAN) and techniques for data transfer [4, 5].

Data & Knowledge Infrastructure. Today, the modern trend in data and knowledge storage is the use of Cloud Computing services (SaaS, PaaS, IaaS) that offer high flexibility, global access, low cost and increased data security [1, 2, and 15].

Decision-Making Infrastructure. It is the top level of the system and includes decision makers (Managers) and computational models based on Artificial Intelligence (Neural Networks, Fuzzy Logic, Genetic Algorithms, etc.) [8, 14, 17, 18, and 20].

V. The Model for Multi-Objective Search of the Optimal Quality Solution

The Multi-Objective Optimization Problem for finding the optimal quality solution is formulated in model (1) and is composed of the number of services offered by the Smart City and the number of equalities and inequalities of constraints:

$$\begin{cases} Q^{S_m}\left(X^{S_m}\right) \to opt^{S_m}, \\ \text{Subject to: } f_m\left(X^{S_m}\right) \le B^{S_m}, \\ \qquad g_m\left(Y^{S_m}\right) \le C^{S_m}, \qquad \forall m = \overline{1, M} \\ \qquad X^{S_m} = \left\{x_n^{S_m} \ge 0, \forall n = \overline{1, N^{S_m}}\right\}, \\ \qquad Y^{S_m} = \left\{y_n^{S_m} \ge 0, \forall n = \overline{1, N^{S_m}}\right\}. \end{cases} \quad \square\square\square$$

In model (1) we have:

$Q^{S_m}\left(X^{S_m}\right)$ is the set of objective functions for quality assessment for the service defined by the set of state parameters X^{S_m};

opt^{S_m} is the Service Quality Assessment target function S_m which is made up of two basic objectives: min^{S_m} - the target sub-function for Service Provider Agents, and max^{S_m} - the target sub-function for Service Consumer Agents;

$f_m\left(X^{S_m}\right) \le B^{S_m}$ are the set of constraint function state parameters X^{S_m} of the service S_m, and B^{S_m} - are the set of limit coefficients (financial resources, conditions of use/application/operation, etc.) for access to the service S_m;

$g_m\left(Y^{S_m}\right) \le C^{S_m}$ is the set of constraint functions for action parameters Y^{S_m} on the service S_m, and C^{S_m} - is the set of limit coefficients of available resources (financial, technological, technical resources, etc.) for the provision/generation/production of the service S_m.

The process of finding the optimal solution for the quality of service is performed based on game theory with Nash Equilibrium condition [21, 22]. The process of service generation in Smart City is a competitive decision-making process between the set of Service Providing Agents and the set of Service Consuming Agents. In this competitiveness, the resources and knowledge available to the sets of Agents are involved. In the modelling result the optimal condition that satisfies both parties: the SPA and SCA set was obtained.

VI. Conclusion

Everyday life in Big Cities is becoming more complex. From this point of view, in order to achieve quality services, decision-making processes require the involvement of modern techniques and technologies based on Artificial Intelligence models. The Smart City concept itself, defines service as a set of fundamental quality characteristics aimed at meeting the needs and improving the quality of life for its citizens.

The decision support system for quality services offered by Smart City is defined as a Multi-Agent System operating in an N-dimensional space. According to its functionality the multitude of Agents is divided into three groups: Service Providing Agents, Service Consuming Agents, and Service Consuming - Service Providers Agents. Based on this concept, the research problem was formulated which foresees the development of a Multi-Agent System for decision support in order to ensure quality services provided by the Smart City using Multi-Objective Optimization models and game theory (Nash Equilibrium).

The way of interaction between the Agent groups is specified by the block diagram which, besides Service Providing Agents and Service Consuming Agents, foresees the involvement of a supreme supervisory body of knowledge models (Service Quality Assessment Agents) for the assessment of service quality.

The functionality of the decision support system for quality services offered by the Smart City is presented on 5 infrastructure levels: Agents Infrastructure, Services Infrastructure, Communication Infrastructure, Data & Knowledge Infrastructure, and Decision-Making Infrastructure. This functional hierarchy allows structuring and optimally distributing tasks and services in the

Smart City system.

The Multi-Objective Optimization Problem of quality parameters is defined based on a model of mathematical expressions in relation to the number of services offered by the Smart City and the number of equalities and inequalities of constraints. The mathematical models of the constraint functions are developed in relation to the limit of resources available for service provision and the limit of resources available for service consumption.

Future research is planned in the hardware design of Agents and real-time functional testing of the models presented in this paper.

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