Intelligent Decision Making Support System for Smart City Governance and Management

Vasily Popovich
Hi-Tech Research and Development Office Ltd.
St.Petersburg, Russia
popovich@oogis.ru

Tatiana Popovich
Hi-Tech Research and Development Office Ltd.
St.Petersburg, Russia
t.popovich@oogis.ru

Oksana Smirnova
Hi-Tech Research and Development Office Ltd.
St.Petersburg, Russia
sov@oogis.ru

***Abstract*—In this paper we discuss the process of development of a new innovative intelligent decision making support system for city environment governance and management. The main point made in this work is integration of modern GIS technologies, information technologies and decision making tools into city governance and management processes. This system was developed as a part of international collaborative project CRISALIDE under the international program ERA.Net RUS PLUS.**

***Keywords*— smart city, intelligent GIS, decision making support system, city management, city governance**

I. Introduction

It is hard to argue that development of modern cities is happening at a very rapid rate. The quality and pace of city life is greatly influenced by appearance of new innovative scientific and technological solutions, fast pace of economic growth, significant increase of the population. All of that are implied dynamic of today's cities.

In order to encompass and implement all the innovations and modern information technologies, new concept was introduced. Such concept is now widely known as smart city. Basic components of such concept are energy efficiency, environmental friendliness, safety, accessibility of various services, electronic services, etc.

The use of decision making support system is pretty common in different technical and organizational systems. However, in context of city governance and management they have not yet found concrete application in practice. Several ready-made solutions of decision making support system (DMSS) can be found on the market (R3 by SAP, Business one by Microsoft, 1C). But it should be noted that the implementation of these systems is an extremely labour-intensive, technically complex and very costly activity. We propose a development of a new DMSS for governance and management of city environment. The proposed DMSS shall possess a set of innovative properties, major ones being the following: reasonable cost of initial product, openness and flexibility, relatively low life-cycle cost, friendliness to users without special training in computer science.

This paper outlines the design of the intelligent decision making support system for city governance and management for the CRISALIDE project under the international program ERA.Net RUS PLUS. The goal of this work is to create conditions for effective decision-making for city management as entire economic and social system. Application of modern information technologies for strategic and operational management of the city environment could bring significant economic benefits.

II. Problem Statement

Intelligent DMSS is a complex software product that includes intelligent subsystem based on first-order predicate logic and on other mathematical approaches, ontology system, intelligent GIS, the library of mathematical and simulation models, scenario system, computer communication systems and a number of other auxiliary systems (Fig. 1).

Fig. 1. Basic components of intelligent decision making support system.

Investigation of processes of city environment governance and management as an object of automation incorporates the following stages [3]:

- Analysis of current level of automation of city administration.
- Engineering of city administration business processes.
- Characteristics of existing CRISALIDE's elements.
- Investigation of inherited automation systems.
- Adaptation of basic technologies for CRISALIDE's building.
- Refinement (development) of ontology system.
- Refinement of CRISALIDE's architecture.
- Development of technical specification for CRISALIDE project's advancement.

On the first stage it is necessary to analyze the means and systems of automation (MSA) which are already implemented into city administration process. We also need to estimate principles and duration of MSA creation. Finally, one should define a list of organizations involved in MSA creation.

The business process engineering implies analysis of horizontal and vertical relations. Requirements for business processes' description include, above all, the following actions: (1) analysis of government's city environmental management cycle, (2) analysis of levels of city management (strategical, operational, tactical), (3) analysis of management phases (initial data processing, concept development, decision-making, planning and execution, control and analysis of the activities).

Here strategical level assumes city administration activities for the long-term perspective and reflects global trends of city administration activities. Operational level reflects task-solving for the middle-term perspective (business processes of a separate city departments). Tactical level incorporates task-solving for the short-term perspective from real-time to a year (business processes of a city area, an important location or a situation).

Since engineering of business processes for city environment is very complicated process, these business processes (BP) should be grouped according to their importance: (a) basic BP identifies key results (strategic goals) of smart city functioning, (b) auxiliary BP provides basic BP and supports smart city infrastructure, (c) sustaining BP support all basic and auxiliary processes.

Theoretical support is an important component of life-cycle of MSA. Theoretical framework of CRISALIDE project is essentially based on scientifically justified interconnected models, algorithms, methods intended to justify suggested ideological, methodological and technical solutions proposed in the project.

Intelligent decision making support system (DMSS) for city governance and management provides:

- acquisition, processing, storage and representation of information from different means of city environment monitoring, of information about city objects and connected situations;
- access to data bases and knowledge bases in real time scale; ontological analysis of city environment from the point of view of city infrastructure, housing stock and land-use management;
- analysis and prediction of dangerous and critical situations and of potential threats that influence life safety in the city environment (ecological and industrial disasters, traffic accidents, acts of terrorism, etc.); risk estimation;
- recommendations for decision makers on city environment management in the context of creation of city strategic and territorial plans, city strategy, promotion of e-Government, management of city infrastructure, housing stock and land-use;
- documenting of decision making process, interaction between decision makers and other users, estimation of the quality of decision-making support;
- modelling of scenarios of complex spatial processes evolution in arbitrary scale with their visualisation on digital map;
- confidentiality of information, sustainability, accuracy, authenticity, communicativeness of information and analysis of all fact that influence decision-making.

Major end-users of CRISALIDE system are central and local government authorities, public and private enterprises that are directly related to functioning and development of city environment. The second group of end-users are construction industry stakeholders. Construction industry is traditionally considered a driver of the economy. Also, the CRISALIDE product may be of interest for investors and businessmen. Enterprises and organisations involved in any way in city environment (owners of retail, commercial areas, warehouses, invest funds, banks, private investors, etc.) may be interested in actual and illustrative information about perspectives of city environment and infrastructure development. Another group of end-users are higher education institutions that train personnel for public service, ministries in the city environment and infrastructure domain. CRISALIDE system can also be adapted for the needs of university management.

Functionality of CRISALIDE implies division of users into the following groups:

- Operators: full-time employees that supervise and control current tasks and take necessary actions in order to normalize the situation in case it overpasses beyond the permissible boundaries.
- Analysts: full-time employees that analyse and select information. They provide decision variants based on their analysis, predict events, determine trends, and prepare information for informative decision-making.
- Heads: administration that set tasks, control their execution, make decisions, report on the activities using provided materials.
- Service chiefs/operational staff: non-employees that make decisions using operational data.

III. Ontology Model for Smart City Governance and Management

By ontology model of city environment we understand a description of basic notions (classes) of city environment, description of objects of city environment, their specific properties and relations between these objects [6]. By city environment's objects we mean engineering communication, transport infrastructure, objects of cultural heritage, industrial and social facilities, services and people. Thus, ontology provides the 'framework' for representation of concepts of subject area and for relations between them.

Ontology of the city environment should include two interconnected ontologies: ontology of city environment as of a subject domain and scenario ontology that describes the behavior of objects in the city environment.

Ontologies are distinguished by uniformity, completeness and consistency of concepts used.

Ontology should (a) eliminate data redundancy, (b) identify and formalize missing data necessary for optimal realization of business processes, (c) take into account specificities of business processes, (d) increase effectiveness of knowledge reuse, (e) take into account processes that take place throughout the life cycle of information system, (f) support processes of harmonization, integration and fusion data within the system.

The process of ontology creation for any information system includes the following steps (Fig. 2):

1) identification of classes (concepts): basic notions from city environment domain;
2) setting up a hierarchy of classes (basic class → subclass);
3) identification of properties of classes: slots and their possible values;
4) filling the slots for class instances.

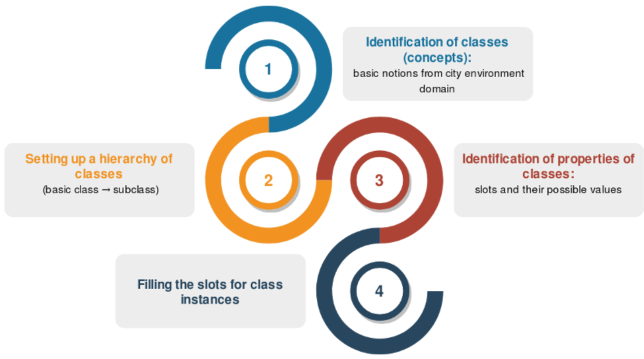

Fig. 2. The process of ontology creation

Basic requirements for the ontology of the city environment, according to [1], are the following:

1) simplicity: expressions and relations must be simple to use;
2) flexibility and scalability: adding of new notions and relations to the ontology must be clear and accessible;
3) universality: ontology must support different types of information (textual, graphical, etc.) and of knowledge about the city environment;
4) expressiveness: ontology must support description of the necessary number of attributes in order to adequately reflect the information and knowledge about the city environment.

Technologies for representation of knowledge about the city environment that are based on ontologies allow to speed up creation of new databases and to keep the existing ones up to date in accordance with information available.

Among the major components of city environment's ontology we can highlight the following:

- information about constructions and buildings;
- information about transport system;
- information about energy system;
- information about environment;
- information about citizens;
- information about urban space use.

On Fig. 3 represent some part of city environment's ontology which is called *Spatial subsystem*. This subsystem includes information about material resources of city economy. Material resources encompass city's territory, all man-made objects. Thus *Spatial subsystem* is divided into two part: *Territory* and *Infrastructure*. *Territory* includes information about all city's territory arranged into groups by the nature of use: *Urbanized territory* (residential areas, socio-economic zones, operating spaces etc.) and *Rural territory* (leisure territories, natural landscape, agricultural areas etc.). Objects that connect various territories are assigned to the *Infrastructure* part.

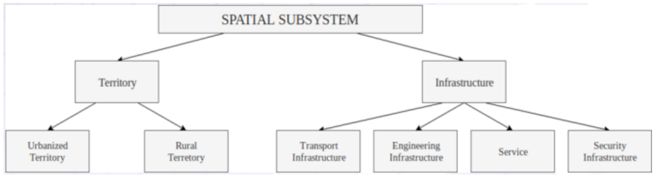

Fig. 3. Example of city environment ontology

The modern approach based on object-oriented ontologies is used for representation of knowledge that constitute the scenarios and the rule set. Development of scenario ontology includes the following steps:

1) Plotting scenario schemes for the simulated situations.
2) Plotting schemes for scenario phases.
3) Implementation of decision blocks into scenarios.
4) Implementation of concrete "elemental" actions from which the scenarios of simulated situations are built.

Creation of ontology allows to:

- uniformity of represent heterogeneous information,
- form a holistic view of the subject domain,
- identify missing components in knowledge,
- increase effectivenes of knowledge reuse.

Therefore, the city environment ontology can be used as a basis for creation of decision-making support system for city environment management. Its distinctive feature is existence of scenario ontology that allows to model the most common activities in city management as well as unique ones. This technology is based on pre-designed rules that allow to automatically use contextual information about the city environment.

IV. General Architecture of DMSS for Smart System

Major elements of intelligent DMSS for city environment governance and management are based on intelligent geo-information system concept. The term intelligent GIS is defined here as GIS that includes integrated tools and/or systems of artificial intelligence (AI) [2]. The central part of the IGIS is a knowledge base that includes ontology of city environment (Fig. 4).

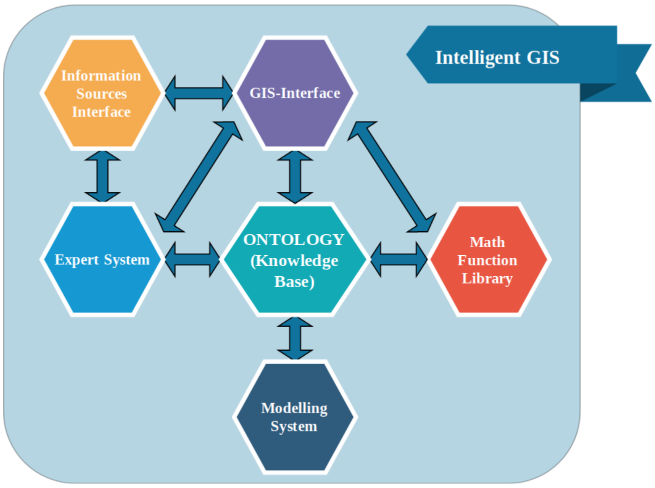

Fig. 4. Architecture of intelligent decision making support system

Various active and passive sensors as well as information systems of global and local level (external sources) can act as sources of information for intelligent decision-making support system for city management. In the process of obtaining data from different sources, the problems listed below may arise. Firstly, duplicated information may appear: information obtained from different sources but about the same city objects. However, similar data about the same object is not necessarily a disadvantage since it increases credibility of data and consequently increases quality of specific decisions. One of the means for solving the duplication problem and increasing the quality of data obtained from various sources is application of concept of integration, harmonization and fusion of data [2]. Data harmonisation is a process of standardization of data obtained from different sources with a common format. Integration of information is a process of bringing together all information about an object obtained from different sources. Data fusion is a process of aimed at obtaining new knowledge about an object through processing of information at hand.

Second problem is the issue of discrepancy between concepts in different systems. To format initial data to one standard, a unified information interoperability model on basis of ontology database was developed. Information interoperability model includes three ontology levels: domain ontology, geographical ontology and upper ontology.

The next component of intelligent DMSS for city governance and management is GIS-interface. GIS-interface is a program component for visual representation of geo-spatial data in various digital formats and of objects stored in knowledge base. It combines different sources of geo-spatial data and program components that execute data processing using traditional methods.

GIS-interface allows:

- to update and display data in real-time mode along with processed results, predicted and modelled data;
- to display all infrastructure of observed area of urban activities;
- to set combinations of algorithms for execution of all stages of dangerous situation modelling (verification, interpolation, prediction).

Library of mathematical functions is one of the important parts of intelligent decision-making support system for city management. Set of functions has to be open for access by any subsystem of IGIS, support changeability and expansion.

For example, for modelling spatial processes associated with dangerous situation development in urban activities location following functions from library can be applied:

- mathematical model of different city's dangerous situations;
- search in location of rescue operation and etc.

To increase the quality of specific decisions made by user it is necessary to include prognostic models in mathematical functions library, i.e. such models, that allow to obtain estimation of dangerous situation development in future instances of time, based on data obtained to the current point of time.

It should be noted that any function from mathematical functions library can be used in creating production rules for expert system.

Expert system (ES) is a system that uses expert knowledge (knowledge of specialists) to provide qualitative problem solving in the given subject area. Such systems can represent knowledge, have capability to interpret (research) its processes-reasoning and are intended for subject areas that require special abilities and a lot of experience.

Expert systems in DMSS can be applied for solving of the following tasks:

- extraction of information from initial data;
- situation recognition;
- prediction;
- structural analysis of complex objects (e.g. districts, city areas, parts of terrain);
- diagnosing problems in DMSS functioning and in connected technical complexes;
- configuring complex multiunit systems (e.g. distributed computer systems);
- planning execution sequence of operations leading to the chosen goal and etc.

It is important to note that this list is far from complete and is constantly extended along with development of geoinformation technologies and artificial intelligence (AI) methods.

Technological process of creation of the expert system demands particular form of interaction between its creator, also called as knowledge engineer, and one or several experts in the given subject area. Knowledge engineer “extracts” procedures, strategies, empirical rules from experts, that they use to for problem solving, and “implements” these knowledge into the expert system.

Typical expert system integrated into IGIS contains the following major parts:

1) Knowledge base that contains rules (or knowledge in different forms of representation) that use these knowledge as basis for decision making.

2) Inference machine that realises process of solution search with use of knowledge from knowledge base.

3) User's interface that provides external interaction with IGIS.

4) Explanatory subsystem that informs the user about chosen decisions.

5) Knowledge base editor that allows to add/delete knowledge from knowledge base.

Aside from the listed components, the expert system, integrated in DMSS, can contain other program means that are specified by the subject area.

Major and essential component of the expert system is the knowledge base. Creation of the knowledge base is a separate and reasonably complicated task.

DMSS modelling system is intended for computer modelling of various spatial processes and also for visual generation of corresponding scenarios of processes development based on expert systems technology and represented as ontology database. Visual representation of the modelling allows the user to effectively estimate occurring process.

Modelling system allows us to solve the following tasks:

1) Building models of complex spatial processes based on their description in form of visual scenarios that are represented as two-dimensional digraph (block-scheme) where nodes are separate scenario tasks and decision making points in which scenario branches on various execution routes depending on satisfaction of specified conditions. Scenario tasks can be executed both sequentially and in parallel, depending on block-scheme. For merging parallel branches, special nodes "connectors" are used. Scenario tasks consist of individual atomic actions and are as well represented as block-schemes connecting atomic actions. Task's actions can also be executed both sequentially and in parallel, depending on task's block-scheme.

2) Construction, debugging and testing of scenarios by field of study specialists mostly with use of visual drag-and-drop of icons, corresponding to tasks, solutions and actions, to the scenario and task scheme form and connecting them in accordance with scenario logic.

3) Scenario execution of complex spatial processes in optional time scale against digital map background, represented as moving simulated point objects with changing form, size, location, colour, transparency and etc. extended objects along with messages on natural professional language.

4) Interaction of number of complex processes, modelled on one as well as on several machines in network.

5) Manual object and process control option, modelling process in general (start/stop, time scale change, maps and etc.), scenario replay from control point, time jumps and etc.

Requirements for mathematical support are the following:

1) Mathematical support of justified decision-making carried out by Government official on all management levels.

2) Mathematical models, algorithms and methods, implemented into informational and analytical, informational and calculating and calculating components of specialized software in CIS.

3) Completeness and adequacy of mathematical description of management processes implemented in Government.

4) Requirements specified by Government's management system.

Mathematical models, algorithms and methods implemented in CRISALIDE must have a structure convenient for their integration into specialized CRISALIDE's software. A list of mathematical models, algorithms and methods must be structured in accordance with levels and stages of management.

Informational support should allow to build dynamic information models for city environment management system which contain data corresponding to real parameters of city environment at any given moment in time. Dynamic information models of the subordinate managed objects should become the components of these models.

Dynamic information model of each component of DMSS should represent states of information objects and their interaction, organized in accordance with a specified set of rules.

The project must have formulated requirements for technical support and reliability of CRISALIDE's components that include:

- Typical exploitation model towards which the quantitative reliability requirements are applied.
- Failure criteria for stationary operating condition referring to which the reliability requirements are formed.
- The value of required continuous non-failure operating time.
- Limit states criteria referring to which the durability requirements are formed.
- Protective properties of CRISALIDE's components' criteria referring to which preservation requirements are formed.

Considering the specificity of CRISALIDE functioning related to processing of information that may be confidential and may contain commercial secrets, security and data protection system must be an integral part of the system and must evolve along with it. While working on the project, one must estimate levels of security of confidential information and commercial secrets.

V. Conclusion and Future Works

Implementation of CRISALIDE project will allow to solve the following tasks: to stimulate the development of e-government, to improve the quality of governmental management through creation and implementation of modern information technologies. The developed DMSS will allow to predict directions of evolution of city infrastructure not only for the city as a whole, but also for the separate regions and districts. It will allow to detect deficit or surplus of industrial and\or infrastructural objects and also to take into account socio-economic aspects of development of municipalities and regions. These factors can easily influence business projects' profitability.

CRISALIDE project will not only allow municipalities to manage city environment, but it also will provide means to obtain information, to plan and to simulate city development with consideration of influence of activities of non-governmental enterprises and organisations.

Moreover, CRISALIDE system allows to adapt its set of tasks to the sphere of activity and demands of the client. It can be equipped with a set of management tasks, strategies and planning scenarios for the specific industry, business, enterprise or organisation.

REFERENCES

[1] P. Korpipää and J. Mäntyjärvi "An ontology for mobile device sensor-based context awareness," in Proceedings of CONTEXT 2003, vol. 2680, 2003, pp.451–458.

[2] V. Popovich et al., Intelligent geographic information systems for monitoring maritime objects. R.M. Yusupov, V.V. Popovich, Eds. St. Petersburg: Nauka, 2013.

[3] P.Elisei, V.Popovich, M.Schrenk "CRISALIDE – Consept of Corporative Information System for Governance and management of Digital City," in Proceedings of REAL CORP 2019, 2019, pp. 191-198.

[4] V.Popovich "Space Theory for IGIS," in Information Fusion and Geographic Information Systems, Springer-Verlag BerlinHeidelberg 2017, pp.3–14.

[5] J.-C. Thill "Is Spatial Really That Special? A tale of Spaces," in Information Fusion and Geographic Information Systems: Towards the Digital Ocean, Lecture Notes in Geoinformation and Cartography, Springer-Verlag Berlin Heidelberg, 2011, pp.3–12.

[6] O.Smirnova, T.Popovich "Ontology-based model of a smart city," in Proceedings of REAL CORP 2019, 2019, pp.533–540.

[7] Popovich V., Borodkin L., Shrenk M. Human's Digital Space in a Digital City. Real Corp 2016, 22-24 June 2016.