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Modeling and using intelligent multi-agent system in smart city: ontological approach

The article discusses the problems of using intelligent multi-agent systems in solving a set of problems in managing and planning processes in a modern city. The concept of constructing intelligent multi-agent systems in systems that support the concept of a Smart City based on ontological modeling is considered. The proposed approach makes it possible to build formalized ontological models and flexibly configure an intelligent multi-agent system to solve problems of coordinating the work of all services of a modern city. The transition from a city in the usual sense to a Smart City is extremely necessary due to the huge gap between the increased complexity of the political, social and economic environment of modern settlements and the already outdated administrative and technological infrastructure, unable to function effectively in the new conditions. The article shows the need to rethink the key elements and general concept of the Smart City. The definition of a Smart City as a multiagent intelligent system is presented. An ontological approach is described, which involves minimal interference in the work of city services, ensures smooth changes and can be carried out by several teams of specialists in parallel. Currently, the method is used by the authors in a project aimed at developing Smart City – a digital ecosystem of services that allows achieving a synergistic effect between various subsystems (transport, ecology, energy, urban design, etc.).

***Keywords**: modeling, ontology, metaontology, information system, multi-agent system, intelligent multi-agent system, Smart City.*

Introduction. Nowadays, more and more attention is paid to the concept of "Smart City". The use of modern technologies to design a Smart City to achieve a synergistic effect between various subsystems (transport, logistics, security, energy, administrative sector, etc.) is described in [1].

In [2, 3] the Smart City concept is shown for:

– narrow tasks (for example, optimizing energy consumption, improving air quality, noise insulation, regulating transport systems);

– global projects (for example, maintaining the identity of a particular city/village and its urban structure, i.e. historical, cultural, environmental or aesthetic aspects).

An approach is used in a broader sense in the form of the concepts of "Smart Village" or "Smart Region".

The relationship between energy, transport and city infrastructure is of great interest [4].

Numerous goals of sustainable development of the city's infrastructural environment can be achieved with the help of possible innovative solutions, in particular, such as:

– optimization of the functioning of all city services;
– reduction of travel time to places requiring the intervention of relevant city services;
– improvement of the operation of transport support of all services of the city (choice of routes, reduction of time of arrival to the city of an accident, fire, etc.);
– reduction of energy consumption by services supporting the infrastructural functioning of the city.

Analysis of recent research and problem statement. In [5, 6] it is considered as a Smart City, being a complex system, to achieve the effective functioning of which cooperation between architects, lawyers, investors, experts in the field of transport and energy, information technology, politics, and sociology is necessary.

The use of information received from the target audience makes it possible to adjust behavior and communications between representatives of the city government and city residents, which gives every citizen a feeling of involvement in the life of the modern city [7].

New technologies (for example, virtual or augmented reality) contribute to more effective planning and involvement of residents in city development.

From a technical point of view, the Internet (Internet of things, people, energy, services) is used for the general exchange of information [8, 9]. From a systems point of view, cyber-physical or socio-cyber-physical systems are used [10, 11].

In the Smart City, the management of urban structures changes, moving away from standard dynamic plans to adaptive control algorithms that ensure coordination of territorial units [12, 13].

All elements of a Smart City can be represented by corresponding *Demand Agents* and *Resource Agents*, which interact with each other and represent all existing requests and resources [14, 15].

Such a multi-agent model, being a digital platform with a limited and time-varying amount of resources, contributes to the dynamic modification of the functioning of the Smart City (*Smart Resilient City*) [16].

The multi-agent approach is a view of the city as a digital platform and ecosystem of smart devices, where agents of people, things, documents, robots and other components can directly interact with each other, based on the “order-resource” principle and providing the most optimal management solution.

Such a platform creates a smart space and becomes the basis for the self-organization of individual citizens, their groups, and entire systems in conditions of sustainability and adaptability [17].

In the Smart City concept, an important role is played by the factor of interaction (interface) of technical systems of different categories of citizens (children, pensioners, youth, people with different levels of IT literacy, etc.) [18, 19].

To assess the Smart City, different methodologies are used, for example, the Smart City Index [20], which includes an assessment of the level of “digitalization” of various processes of urban subsystems (for example, security, energy management, heat supply management, public transport management).

The purpose and tasks of the research. The purpose of the article is to research and solve problems associated with the management of urban structures (the functioning of which is supported by appropriate transport support), when all elements of a smart city are represented by interacting demand agents and resource agents, which are elements of the corresponding intelligent multi-agent system, design, development and operation which is performed using ontological modeling.

Materials and methods of research. One of the promising approaches to the creation of intelligent systems is the use of multi-agent technologies [21, 22].

Multi-agent system of the modern city. A multi-agent system consists of autonomous software objects (agents) capable of perceiving a situation, making decisions, and interacting with other agents.

The design of intelligent multi-agent systems involves the use of parallel and asynchronous interactions of software agents of the system until the agents reach the so-called “competitive equilibrium”, which is interpreted as a kind of “consensus” (balance of interests), when none of the agents can improve their performance anymore.

This approach makes it possible to switch to a distributed solution of the problem in the modern city, where the interests of all participants (subjects) of planning and management of the modern city and his services can be presented and taken into the account.

In this case, the processes of planning and management in the modern city and his services can be considered as a non-deterministic process of self-organization of agents, since each agent makes the decision on its own to establish or break connections both with the system itself and with other agents of the system at an arbitrary point in time, eliminating possible conflicts with other agents.

Designing intelligent multi-agent systems requires a lot of efforts from developers both at the design and development stage, and at the stage of implementation and operation.

The basic principles of building multi-agent systems based on ontologies were formulated in [21, 22], which shows the structure of a typical multi-agent resource planning system, the data model of which is built on the basis of a project management ontology.

The presented work develops well-known principles in terms of creating basic ontology for planning and developing models and methods for making decisions in planning and management in the modern city and his services, as well as in implementing complex of software tools, in which ontologies allow not only expanding the set of restrictions, but also rebuilding scenarios for providing subjects of modern city with information resources of the system [23, 24].

A system is considered complex multi-agent if it has the following properties:

– openness;
– adaptability;
– the presence of many partially autonomous and interconnected components (agents);
– lack of centralized management.

The overall behavior of such systems consists of connections between constituent agents whose autonomy is limited by the factors imposed on them by the system to which they belong. Table 1 shows the classification of multi-agent complex systems.

Table 1. **Classification of intelligent multi-agent systems**

Random	Complex multiagent	Deterministic
Uncertainty = 1	0< Uncertainty <1	Uncertainty = 0
Full autonomy of agents	Partial autonomy of agents	Lack of autonomy for agents
Unorganized	Self-organization	Organized
Unpredictable behavior	Emergent behavior	Predictable behavior

Agent *connectivity* indicates the number of agents with which the original agent can interact.

Agent *autonomy* indicates the degree of freedom of behavior of the agent.

The *complexity* of the system increases as the autonomy of the agents increases. In extreme cases, when agents are given complete freedom, the behavior of the system becomes random.

Emergence indicates that a system has special properties that are not inherent in its individual elements. These properties appear as a consequence of the interaction of agents.

The property of *nonlinearity* is inherent in systems in which the connections between agents are nonlinear.

Disequilibrium is a property indicating the susceptibility of operations to the influence of unpredictable destructive events.

Self-organization is a property that manifests itself when disruptive events occur (receipt of an unexpected request, delay, falsification, attack, etc.), then the system urgently identifies the affected areas and is rebuilt to eliminate/reduce the effect of the disruptive event.

Self-organization can lead to self-development, as a result of which agents self-organize to improve the performance of the system.

Co-evolution is a property of multiagent systems that allows them to develop together with their environment.

Smart city is an adaptive, resilient and sustainable city that offers its guests and residents a high standard of living, work and entertainment with minimal impact on the environment.

Adaptability, stability in development and the ability to quickly recover are emergent properties of multiagent systems [25 – 27].

It follows from this that in order to transform a city into a smart one, it needs to go through "digitalization", i.e. be based on technologies such as: multi-agent systems, artificial intelligence, Internet of things, social networks, etc., as well as a set of necessary sensors [19].

Problems of the modern city. The complexity of effective city management in new conditions is discussed in [20, 28]. Among the important problems of urban "space" we should, in particular, highlight:

– the presence of unorganized, environmentally harmful services provided to city residents;
– lack of adequate communication channels between city residents, guests and city administration;
– lack of monitoring of the quality of services and knowledge about effective city management in a complex environment [29];
– imperfect methods of strategic planning.

In a typical modern city, various types of services are provided, including:

– education;
– health services;
– social services;
– roads and transport;
– food supply;
– water supply;
– sewerage;
– waste management;
– economic development;
– urban planning;
– public safety;
– environmental health;
– tourism;
– entertainment;
– construction;
– housing services;
– tax collection.

Unfortunately, in our time, each important service is provided separately, and there is practically no coordination of services of the city.

This management method leads to a significant waste of resources, a significant threat to the environment and an increase in the number of diseases associated with its pollution. As a result, the number of unpredictable events increases (eg, policy changes, changes in service demands, unsuccessful use of resources, etc.).

Important factors in city government are, in particular, a rigid, departmental structure that interferes with the coordination of services, and the use of outdated technologies that cannot cope with the dynamism of city life. Due to the limited knowledge of individual subjects, none of the personal ontological and cognitive models can claim to be an exhaustive conceptual representation of problematic situations that arise when managing a city.

By exhaustive conceptual mapping we mean:

– identifying all, including the so-called "hidden" prerequisites for the emergence of a problem situation;
– knowledge and understanding of cause-and-effect relationships between factors separated in space and time that determine the symptoms of a problem situation.

Obtaining a description of a problem situation (its conceptual representation), which is recognized by all participants in the processes in the Smart City (in particular, the city administration, city services, city transport, transport infrastructure, vehicles that provide and support the work of city services, residents and guests of the city, etc.), involves the implementation of an iterative procedure based on solving the following interrelated tasks:

– formation on the basis of personal ontological models of individual subjects (participants in processes in the Smart City, especially transport that supports the functioning of all city services) of an ontological model of a problem situation;

– construction, based on personal cognitive models of individual subjects, of a cognitive model of a problem situation recognized by all interested parties.

During the implementation of the iterative procedure, the personal ontological and cognitive models of individual subjects (participants in processes in the Smart City) are adjusted.

The cognitive model of a problem situation serves as the foundation for the subsequent presentation of a problem situation in the form of a multi-connected control object, which makes it possible to formulate the specification of the corresponding intelligent multi-agent Smart City system using the formation of a conceptual space, strategy and agents of the system.

The reasons for the occurrence of problematic situations, in addition to errors caused by the mental activity of subjects, include, in particular:

– lack of knowledge about the true causes of these situations;

– limited conceptual representation of problem situations; insufficient potential of the models used to represent the PS in the form of a multi-connected control object.

The basis for developing a consolidated solution to resolve problem situations in the city is the identification (both of the situation itself and its components) based on formalization in the form of appropriate ontological and/or cognitive models.

The set of models of problem situations in the city creates the prerequisites for a better understanding of the content of these situations. Studying the properties of an object through modeling creates the basis for forming a consolidated opinion on approaches to resolving problem situations in the city.

One of the tools for constructing formal models of a Smart City is the apparatus of cognitive modeling, the apparatus of ontological modeling is focused on formalizing the weakly structured knowledge of subjects involved in resolving problem situations that arise, in particular, when:

– management of various Smart City services;

– solving problems related to infrastructure facilities of the Smart City.

Transforming the modern city into Smart City. Let's consider a city where there is a local government body – the city administration, responsible for serving citizens. This administration decided to improve the quality of services and reduce the costs of their operation.

A top-down approach to solving a problem, attempting to create a requirements specification for the entire city before work begins, is unacceptable in a dynamically changing urban environment, since the requirements become outdated even before they are completed.

The proposed evolutionary transformation method can achieve smooth transformation.

Frequently changing requirements dictate the use of the proposed method:

Consider all services (including both direct transport and those provided to city services) from the point of view of their priority (importance, value) for the city.

Create a specification of requirements to improve the quality of the selected service.

Develop and implement an adaptive scheduler only for the selected service.

Evaluate and update the solution demonstrating an increase in target indicators.

Select the next service and repeat steps 2, 3, 4, making sure that they cooperate/compete with existing service services.

As the number of changed services increases, it is necessary to constantly monitor and make changes directly to the Smart City.

At the same time, it is necessary to ensure continuous access to qualified specialists to maintain and improve the urban ecosystem, which will allow it to be supplemented with new services capable of self-service and self-improvement.

Note that complex adaptive systems can work effectively in complex conditions. The rigid structures of deterministic systems break down when placed in complex environments, as seen in many declining urban economies around the world.

At the same time, complex structures easily adapt to changes and are able to quickly recover/change under external influences, which makes them more stable. This implies the need to find a way to transform a modern city into a complex adaptive urban system.

The urban system is required to be sustainable [30]. The evolution of Smart City services can be illustrated using the example of urban transport using different types of energy carriers.

The increase in pollution from diesel vehicles in large cities is already critical. In this case, intelligent adaptive planning helps accelerate the transition from diesel to electric vehicles and initiates the expansion of electric vehicle charging points.

Multi-agent planners in Smart Cities are capable of ensuring the interaction of city services in order to maximize Smart City performance indicators.

A typical city service consists of:

– the Real World resources and needs;

– the Virtual World software agents-schedulers of the Real World resources in real time;

– knowledge base containing information about services that support the functioning of the city and its services;

– interfaces for transmitting information about events from the Real to the Virtual World, as well as instructions for transferring resources from the Virtual to the Real World.

Application of service concept in the Smart City system. Let's consider an example of the work of emergency response services (ambulance service, fire service, rapid mine clearance and response service, gas service, water utility services, power grid services, heating network services, police) in the Smart City.

One of the approaches to formalizing knowledge in the Smart City concept is based on the use of appropriate ontological models.

They can be presented in the form of corresponding ontographs with a description of the main entities of the subject area in the form of classes, attributes and relationships.

In this case, both a database (DB) and a knowledge base (KB) are used to adapt the support system for the Smart City concept to provide access to services [19].

The task requires:

– formalization of knowledge about all aspects of the Smart City;

– providing easy access to databases and knowledge bases for various services;

– supporting interaction on digital platforms and ecosystems [16].

A city model based on ontologies can identify major objects such as buildings, roads, transport, bus stops, traffic lights, energy sources, recreational areas and others.

These objects can also have a detailed description – the building can be the restaurant, the business center or the residential building with many properties – attributes (number of floors, date of construction, etc.).

The ontological model also describes people (their activities, requests, requirements and business processes in which they take part) [26, 27, 31, 32].

Formalized knowledge can be used by city services not only as a source of raw information, but also to adapt to the situation and adjust work, ensuring the sustainability of city development.

The use of ontologies (ontological models) is especially relevant when it is necessary to understand the essence and structure of the subject area under consideration (including knowledge and data describing the objects of this subject area). In the problem under consideration, this is the understanding of employees of the relevant city services and/or software agents of an intelligent multi-agent system.

Ontologies allow you to reuse knowledge about objects in the subject area when solving different classes of problems. Formally, the ontological model is specified by the set [5, 6]:

$$O=\{C, R, A\}, \tag{1}$$

where O is an ontology;
C is a set of objects in the subject area;

R is a set of relationships between the objects of the subject area;
A is a set of axioms (laws and rules that describe the laws and principles of the existence of objects in the subject area).

In the subject area under consideration:

$$O_{SS} = \{C_{SS}, R_{SS}, A_{SS}\}, \quad (2)$$

where O_{SS} is an ontology that shows such a subject area as the life of the city (all its services),
$C_{SS} = \bigcup_i C_{SS_i}$ – set of objects of each city service (C_{SS_i}),
$R_{SS} = \bigcup_i R_{SS_i} \cup \bigcup_{i,j} R_{SS_{ij}}$ – set of relationships between objects within each city service ($\bigcup_i R_{SS_i}$) and relations between objects of different city services ($\bigcup_{i,j} R_{SS_{ij}}$),
$A_{SS} = \bigcup_i A_{SS_i}$ – a set of rules and laws (including regulations) that determine the functioning of city services (C_{SS_i}).

For the design of ontologies, there is a special toolkit - ontology editors, which are tools for describing the formal model of the subject area, and also provide additional opportunities for ontology analysis and use the logical inference mechanism.

Protégé is the most popular freely distributed ontology editor, designed to which, in the form of plugins, you can connect visualization tools, build queries to the ontology, and obtain conclusions [32].

The metaontology for the example under consideration, implemented in the Protégé ontology editor [32], is presented on the Fig. 1.

Application of the proposed approach to the Smart City concept includes descriptions of ontologies (which are parts of the metaontology shown on the Fig. 1):

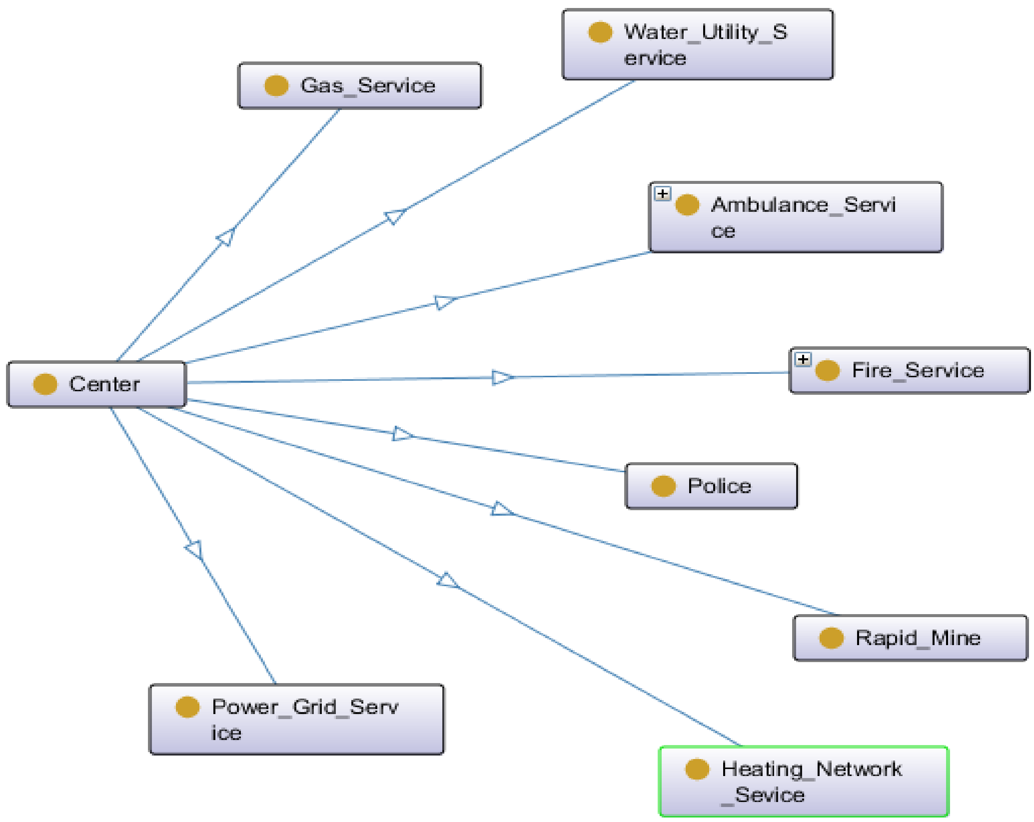

Fig. 1. **Metaontology of the Smart City**

– *ambulance service*, which includes:
- object classes (ambulance, ambulance crew, crew member, medical equipment, route, road, hospital, patient, relative);
- relationships (the crew belongs to the ambulance, the equipment belongs to the crew, the ambulance follows the route);
- properties of object classes (for a crew member: identifier, qualification, availability);

– *fire service*, which includes:
- classes of objects (fire fighting vehicle, fire fighting crew, crew member, fire extinguishing equipment, route, road, fire location, victims, rescued);
- relationships (the crew belongs to the fire brigade, the equipment belongs to the crew, the fire brigade follows the route);
- properties of object classes (for a crew member: identifier, qualification, availability);

– *rapid mine clearance and response service*, which includes:
- classes of objects (demining service vehicle, demining service crew, crew member, equipment for rapid demining and response, route, road, location of detection of an explosive object, demining site (landfill), victims, rescued);
- relationships (the crew belongs to the demining service vehicle, the equipment belongs to the crew, the rapid demining and response service vehicle follows the route);
- properties of object classes (for a crew member: identifier, qualification, availability);

– *gas service*, which includes:
- classes of objects (gas service vehicle, gas service crew, crew member, equipment for quickly eliminating gas pipeline depressurization, route, road, place where gas pipeline depressurization was detected, victims, rescued);
- relationships (the crew belongs to the gas service vehicle, the equipment belongs to the crew, the gas service vehicle follows the route);
- properties of object classes (for a crew member: identifier, qualification, availability);

– *water utility services*, which includes:
- classes of objects (vodokanal service vehicle, water utility service crew, crew member, equipment for quickly eliminating a broken water supply pipe, route, road, location where a broken water supply pipe was detected);
- relationships (the crew belongs to the water utility service vehicle, the equipment belongs to the crew, the water supply service vehicle follows the route);
- properties of object classes (for a crew member: identifier, qualification, availability);

– *power grid services*, which includes:
- classes of objects (energy network service vehicle, energy network service crew, crew member, equipment for quickly eliminating damage to energy networks, route, road, location of detection of damage to energy networks);
- relationships (the crew belongs to the energy network service vehicle, the equipment belongs to the crew, the energy network service vehicle follows the route);
- properties of object classes (for a crew member: identifier, qualification, availability);

– *heating network services*, which includes:
- classes of objects (heating network service vehicle, heating network service crew, crew member, equipment for quick repair of heating network damage, route, road, location of detection of heating network damage);
- relationships (the crew belongs to the heating network service vehicle, the equipment belongs to the crew, the heating network service vehicle follows the route);
- properties of object classes (for a crew member: identifier, qualification, availability);

– *police*, which includes:

- object classes (police car, police crew, crew member, weapon for crime prevention/investigation, route, road, crime scene);
- relationships (the crew belongs to the police car, the weapon belongs to the crew, the police car follows the route);
- properties of object classes (for a crew member: identifier, qualification, availability).

The system under consideration is intended for planning, coordination and management of all city services based on information about objects and subjects of the subject area under consideration, related to the interests of various categories of users, and recommends to the user those resources of the intelligent multi-agent system that meet their information needs.

The considered intelligent multi-agent system uses the ontology representation language OWL and its processing tools [4, 34].

To represent knowledge, ontologies and thesauri of the subject area are used. In this case, the thesaurus is built by the user using the corresponding ontology independently.

The user of the system can access ontologies created by other users, revise them, set the context for obtaining an information resource based on them, copy the necessary fragments from them, but cannot change them.

The intelligent multi-agent system used in the Smart City provides a search for ontologies containing user-entered terms, as well as a search for ontologies similar to the ontology selected by the user.

An ontological model that describes the semantics of interaction between users and resources of an intelligent multi-agent system in the common information space of a Smart City provides knowledge for performing actions related to processes for solving the problems of a modern city and managing these processes.

On the Fig. 2 shows the ontograph [31, 32, 36] of the subject subdomain *Ambulance Service*.

At this stage, it is advisable to write scripts for agents, which will be stored in meta-ontologies and ontologies that describe subject sub-domains corresponding to specific services, and will be available to agents when there is a need to solve a specific problem.

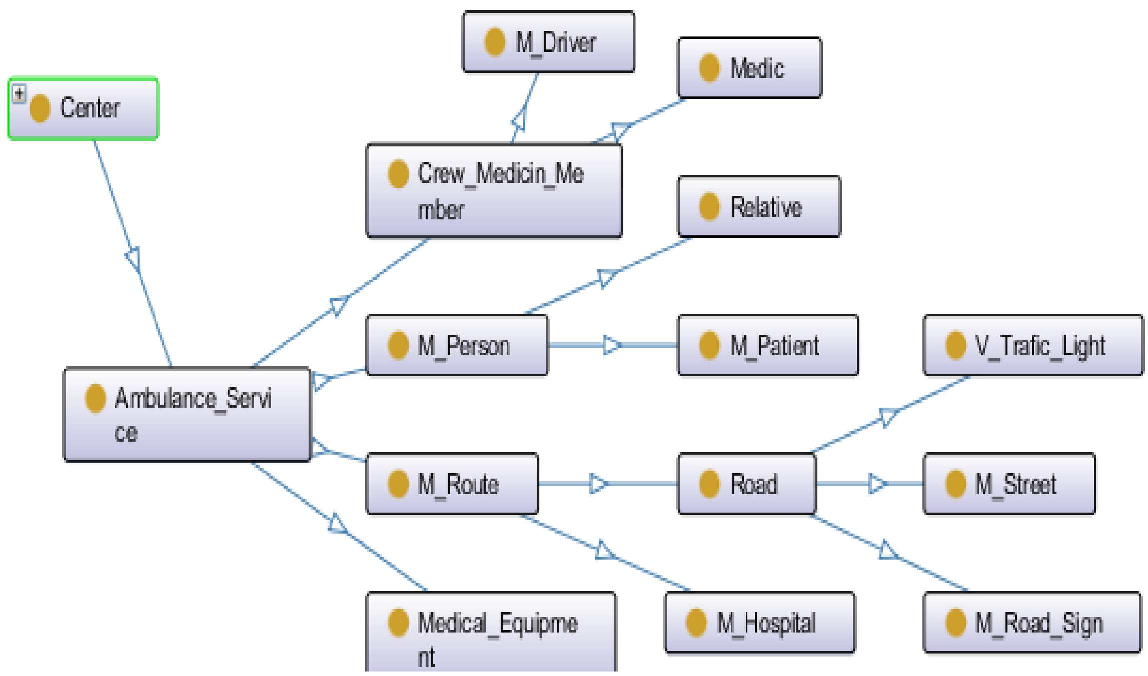

Fig. 2. **Ontograph of Ambulance Service**

All policies, rules and regulations governing the operation of services should also be stored in an appropriate ontology. In addition to the ontology, the knowledge base also contains all data about objects that are usually stored in client databases [34].

On the Fig. 3 shows the ontograph of the subject subdomain *Fire Service*.

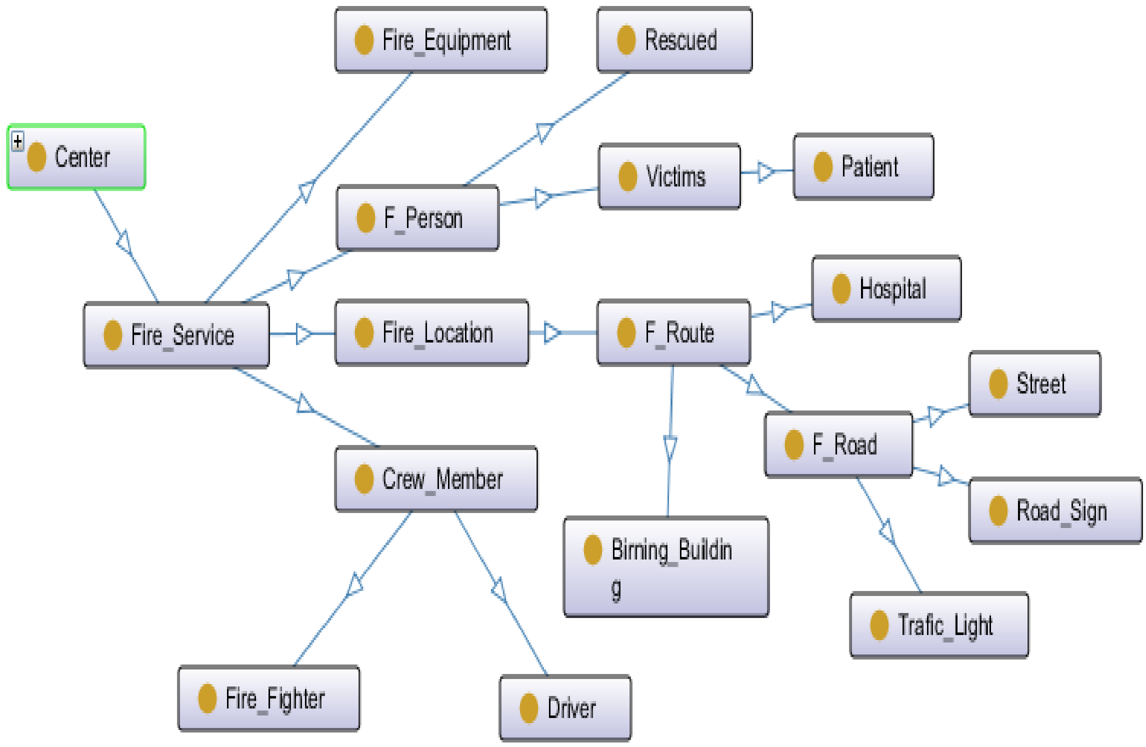

Fig. 3. **Ontograph of Fire Service**

Creation of virtual world of Smart City. The creation of a Virtual World involves the creation of a digital infrastructure that supports the exchange of information between numerous agents of the corresponding intelligent multi-agent system.

The Virtual World is a space in which agents determine conditions ("agree") on the distribution of resources for certain requests.

In the Virtual World of the fire service, the interaction of crew members with each other or with other fire crews, as well as with hospitals, the interaction of roads with routes, patients with hospitals, etc. carried out by exchanging messages between the corresponding agents. Adaptability is achieved by agents matching resource requirements and capabilities.

If, for example, the road to the selected hospital is difficult due to traffic jams on a certain road, the agent of that road will immediately report the problem to the agents of other roads, which initiates an exchange of messages between them to determine a new route to the hospital or determine a route to another hospital. The described example demonstrates the advantage of multi-agency and ontological approach in solving Smart City problems.

Designing interfaces between the Real and Virtual Worlds Information about destructive events occurring in the Real World must be transmitted to the Virtual World, and all planning decisions made by agents in the Virtual World must be transmitted to the Real World.

Initially, information exchange can be carried out through the exchange of messages between people acting as operators (for example, drivers, fire fighters), using their smartphones or specially designed portable communication devices, and agents.

However, the most preferred method is the exchange of information between epyphysical Real World resources (for example, vehicles, robots, conveyors) and agents using Internet of Things technology.

Ambulance route planning is easily expanded, for example by adding doctors and facilities required by patients transported by fire transport.

This requires additional agents. The next step is to add agents to schedule the use of other hospital resources, such as equipment, operating rooms, etc. The design must proceed step by step and each step must be tested in practice before the next one is put into operation.

Conclusion. The transition from a city in the usual sense to a Smart City is extremely necessary due to the huge gap between the increased complexity of the political, social and economic environment of modern settlements and the already outdated administrative and technological infrastructure, unable to function effectively in the new conditions.

The article shows the need to rethink the key elements and general concept of the Smart City. The definition of a Smart City as a multiagent intelligent system is presented.

The method of evolutionary transformation of the activities of city services is described based on the use of an ontological approach, which, in particular;

– provides for the minimization of the so-called "manual" management of the activities of city services due to the connection to the management of artificial intelligence, which is supported by relevant intelligent multi-agent systems;

– ensures the smoothness of changes in the management of the city and its services;

– optimizes the activities of transport support of these services (in particular, due to the laying of optimal routes for the movement of ambulances, fire engines, etc.), ensures;

– supports the simultaneous work of several teams of specialists, avoiding the occurrence of possible conflicts associated with the duplication of some functions in different services of the city.

Currently, the method is used by the authors in a project aimed at developing Smart City – a digital ecosystem of services that allows achieving a synergistic effect between various subsystems (transport, ecology, energy, urban design, etc.).

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Моделювання та використання інтелектуальної мультиагентної системи в smart city: онтологічний підхід

У статті розглядаються проблеми використання інтелектуальних мультиагентних систем у вирішенні комплексу завдань управління та планування процесів у сучасному місті. Розглянуто концепцію побудови інтелектуальних мультиагентних систем, що підтримують концепцію Smart City (розумного міста) на основі використання онтологічного підходу (онтологічного багаторівневого моделювання). Запропонований підхід дає можливість побудувати формалізовані онтологічні моделі та гнучко налаштувати інтелектуальну мультиагентну систему для вирішення задач координації роботи всіх служб сучасного міста. Перехід від міста у звичайному розумінні до розумного міста (Smart City) є вкрай необхідним через величезний розрив між зростаючою складністю політичного, соціального та економічного середовища сучасних поселень та вже застарілою адміністративною та технологічною інфраструктурою, нездатною ефективно функціонувати в нових умовах. У статті показано необхідність переосмислення ключових елементів та загальної концепції Smart City. Наведено визначення Smart City як мультиагентної інтелектуальної системи. Описано онтологічний підхід, який передбачає мінімальне втручання в роботу міських служб, забезпечує плавні зміни та може здійснюватися паралельно кількома командами спеціалістів. Наразі метод використовується авторами в проєкті, спрямованому на розвиток Smart City – цифрової екосистеми послуг, яка дозволяє досягти синергічного ефекту між різними підсистемами (транспорт, екологія, енергетика, міський дизайн тощо).

Ключові слова: *моделювання, онтологія, метаонтологія, інформаційна система, мультиагентна система, інтелектуальна мультиагентна система, Smart City*.