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MODELING OF MANAGEMENT OF INTELLIGENT SYSTEMS IN TRANSPORT

The article considers topical problems of modeling control processes in intelligent systems in transport. Management of such systems also involves control and monitoring of the processes of their design and maintenance. The article proposes an ontological model of process control of intelligent systems in transport. The proposed ontological model is necessary for the formation of a common understanding of the essence of the subject area, which is the transport sphere (transport systems, transport enterprises, vehicles and transport infrastructure). The proposed ontological model contributes to the presentation of knowledge in a form that is convenient for their processing in the intelligent system of transport; ensuring the possibility of obtaining and accumulating new knowledge.

The proposed ontological approach provides multiple use of knowledge and previously developed ontologies. The proposed approach allows the use of modern multi-agent technology, when each agent has its own ontological model. The considered ontological approach to modeling of management of intelligent systems allows to pass to automatic control of processes in these systems (in the presence of the corresponding restrictions).

The developed ontological model of the subject area is planned to be expanded and supplemented with new components, imposing appropriate restrictions. The OWL software code obtained from the simulation results in Protégé can be further used within the knowledge base of the intelligent system, processing this information in various software applications, including Java applications.

***Keywords**: management, design, intelligent system, multi-agent technology, information resources, knowledge base, modeling, ontological model.*

Introduction. The use of modern information and intelligent technologies, various models of processes that occur in different subject areas (SA), contributes to the solution of existing problems of intellectualization of solving problems in different SA (in particular, in transport).

To avoid situation where the costs of designing and maintaining intelligent system (IS) exceed the benefits of its use, it must be manageable and viable. To do this, the processes of designing and maintaining IS (including IS in transport (IST)) should be replaced by the IST process management process. This means solving problems, in particular, designing and maintaining IST using special high-level control mechanisms [1].

The development of IS management systems should be based on the principle that all design decisions that affect the characteristics of IST should be improved in the process of accumulating experience in its use.

In our time, the problems of development, use and maintenance of IS in various SA (including transport) remain relevant and not fully resolved.

The paper proposes the use of ontological approach for formalized description of the IST processes, including the processes of its design and maintenance.

Analysis of recent research and problem statement. Conceptual information resources (InRes) of IS, including knowledge bases, have declarative and structural representation. These InRes can be represented in the form of appropriate models (for example, semantic network, production or hierarchical model, frame or graph model) [2 − 5].

The structure of the model is defined by some meta-information, and each term in it belongs to some class defined by this meta-information.

Meta-information of conceptual InRes can be considered as: its ontology; the grammar that generates this resource; scripts for dialogue with the user when editing this resource; the basis of the query language for this resource from the IST side. Conceptual InRes *IRk* is pair:

IRk = <*MIn, Cont*>, where *MIn* is meta-information and *Cont* is the actual content of this resource.

Nowadays, technologies in which the IS problem solver is built from agents are becoming increasingly popular. These are the so-called multi-agent technologies [6, 7].

In [8], agents are represented as declarative-procedural InRes. In [9], the solver consists of set of blocks, and each block consists of message ontology and set of productions. Moreover, each solver consists of the following InRes:

network of agents that determines which agents are included in the solver;

control graph that allows agents to find recipients of messages they send;

distribution scheme that sets restrictions on the parallelization of agents when executing the solver in multiprocessor environment.

In [10], it is shown that the user interface model can also be represented as declarative InRes, consisting of: task models; SA models; user models; presentation models; dialogue scenario models.

In [11], the behavior of interface is completely defined by declaratively presented model of the interpretation process.

The conceptual system of InRes is included in its meta-information and allows presenting InRes in form that is understandable to those who manage it (the manager) through the process of visualization (in the form of semantic network or text).

To include experts from different SA into the management process, each InRes is associated with its own formally presented conceptual system.

In [12], the means of managing (creating, editing, modifying) declarative InRes (ontologies, knowledge bases, etc.) is the semantic network class editor, which:

interprets meta-information (meta-information is created by knowledge engineer);

generates interface for managing this InRes.

The purpose and tasks of the research. The purpose of the article is to discuss the problems associated with IST management processes (in particular, their design and maintenance), as well as possible methods for their solution using multi-agent technology and ontological modeling of the corresponding SA.

Materials and methods of research. All IST components and connections between them can be represented as appropriate models (semantic networks, ontological models, etc.). In particular, IST can be represented as:

InS = <*KB, TS, CI*>,

where *KB* is the knowledge base (and other *InR*es - databases, ontologies, meta-ontologies, etc.), *TS* is the problem solver that implements the functionality of the system, *CI* is the user interface.

The goals of managing these components of IST are distinct and, to certain extent, independent. This causes the presence in the architecture of the control system of IS the presence of the following subsystems: InRes control; problem solver control; user interface control.

Based on this, in IST control (management) system, there should be components that support the following types of control:

manual control (iterative change by person of IS properties);

automatic control (changing the properties of IS without human intervention);

automated control (mixed type of control) [13].

Manual management of IS components brings their content in line with the content perceptions of users who manage these components. These users (SA experts, knowledge engineers, IS developers, designers, ergonomists, cognitive psychologists, etc.) will be called managers.

In table 1 presents the problems of manual control of IS and ways to solve them.

Automatic management of IS. The problems associated with the automatic control of IS are presented in table 2. The first of them has already been considered in table 1.

Table 1. **Problems related to manual control and methods for solving them**

№	Problem	Solving
1	Heterogeneous classes of control objects: InRes, problem solvers, user interfaces	Declarative representation of relationships between different control objects (using process and process control models, interface models, etc.)
2	Achieving consistency in IS management (IS components are interconnected and their independent management can disrupt these ties)	Representation of InRes to each user-manager in terms of its formally represented conceptual system
3	Heterogeneous composition of the group of user-controllers for each class of control objects	Reduction of the problem of manual management of IS to the problem of manual management of declarative InRes (in other words, representation of all IS components in the form of declarative InRes, in particular, using ontologies and meta-ontologies)

Table 2. **Problems associated with automatic control and methods for their solution**

№	Problem	Solving
1	Heterogeneous classes of control objects: InRes, problem solvers, user interfaces	Use of systems of rules and mechanisms with feedback
2	Heterogeneity of the states of the control object (automatic control during the periods of operation of the object and between these periods)	Use of internal mechanisms (embedded in IS) together with external mechanisms
3	Achieving consistency between automatic control mechanisms and manual control mechanisms	Use of meta-information in mechanisms of external automatic control
4	Different Degrees of Uncertainty in Automatic Control Problems	Use of problem-dependent control mechanisms along with problem-independent ones

The heterogeneity of classes of control objects (in particular, components of IST can be objects) does not contribute to finding common, problem-independent solutions for automatic control problems. Therefore, problem-dependent solutions are also used.

For automatic management of knowledge bases, problem-dependent mechanisms are used (for example, for the ontology of diagnosing the technical condition of vehicle, for the ontology of innovation and investment activities, including transport enterprise).

An example of such automatic feedback control mechanism is iterative algorithm for inductive knowledge base formation, which consists of two asynchronous processes:

1) processing incoming examples from the training sample and transferring the result (set of alternative knowledge bases) to the second process;

2) choosing from many examples of the best knowledge base and updating the working knowledge base.

An example of problem-independent mechanism for automatic user interface management is mechanism for automatic adaptation to user data and characteristics. This mechanism generates visual representation of the interface based on the dynamic characteristics of the user. Problem solvers can be automatically controlled by both problem-dependent and problem-independent mechanisms.

An example of problem-independent mechanism in problem solver is the automatic parallelization of the functioning of agents on multi-agent platform [7]. In accordance with the multi-agent approach, IST management can be carried out at the following levels:

IST subsystems (components) operate in parallel with each other and are launched for execution through the control subsystem based on information about the user's authority;

agents within each IST subsystem interact with each other asynchronously using communication subsystem based on the control graph (control tree, goal tree, decision tree, etc.);

parallelization of agents within IST is controlled by the agent distribution scheme of this IST;

uniform load on the nodes of the computing farm (server, client computers, multiprocessor systems) is achieved by the balancing algorithm.

An example of problem-dependent mechanism is the automatic control of problem solver of expert system for technical diagnostics of transport objects (vehicles, infrastructure transport objects) [14].

The solver control mechanism, when the results of monitoring the knowledge base, performed every time it is changed, makes it possible to reduce the set of tested hypotheses during processing (technical diagnostics) by the solver of each detail (each vehicle node, transport infrastructure object or part thereof, etc.) by based on rigid system of rules.

The consistency of the mechanisms of automatic and manual control is carried out through the use of meta-information in the mechanisms of external control.

Using meta-information allows you to:

present InRes in form understandable for user-managers;

managing users to monitor the process of automatic InRes management (for example, knowledge bases) of the corresponding IS.

With low degree of uncertainty in the automatic control task, the automatic control mechanism is built on the basis of system of rules, and with high degree, it is necessary to use automatic control mechanisms with feedback.

Iterative methods of inductive knowledge formation and automatic adaptation to the characteristics of IS users are built on the basis of feedback mechanisms, and the mechanisms for automatic parallelization of the functioning of agents and automatic adaptation to data are implemented on the basis of rule systems.

Automated management of IS. The problems associated with the automated management of IP are presented in table 3. The first two of them have already been considered in table 1 and table 2.

Table 3. **Problems associated with automated control and methods for their solution**

№	Problem	Solving
1	Heterogeneous classes of control objects: InRes (knowledge bases), user interfaces, problem solvers	Manual adjustment of the results of automatic control. Teaching systems to solve problems.
2	Heterogeneous composition of the group of user-controllers for each class of control objects	Representation of InRes to each user-manager in terms of its conceptual system Use of problem-dependent control mechanisms together with problem-independent ones.
3	Combining manual and automatic control mechanisms	Reduction of the problem of manual control of IS to the problem of manual control of its InRes

Sharing the mechanisms of manual and automatic control provides the opportunity: the user-manager to correct the results of automatic control; show the solution of particular problems that are generalized by automatic control mechanisms and used by the solver.

An example of automated control task is the task of debugging technical knowledge bases, where monitoring the knowledge base regarding selection of diagnostics (states) of transport objects (vehicles or transport infrastructure objects) reveals errors and inaccuracies in this knowledge base. The mechanisms of inductive formation of knowledge bases determine the options for eliminating these errors and inaccuracies, and the SA expert who manages the knowledge base chooses from these options those that he considers the best.

Complex ontology of designing IS of technical objects (in IST − dynamic transport). Let's consider some aspects of building complex knowledge structure in IST using complex ontology as formal theory of knowledge interpretation.

Complex ontology of design, as complex system of knowledge, integrates the analysis and interpretation of heterogeneous information and involves the development of algorithmic and software tools for representing ontological knowledge and working with such knowledge. Among the directions for creating IST ontology system, one should highlight, in particular: *organization ontology*; *project ontology*; *research-topic ontology*.

The implementation of these areas is associated with the solution of problems of representation, search and processing of information using ontological knowledge [15, 16].

In the work, ontological model of managing the processes supported by IST (including the processes of its design and maintenance) was chosen as the model of the ontology of SA.

The model of IST is based on complex ontology and makes it possible to formalize control processes in such dynamic SA as transport. SA under consideration consists of technical, transport facilities (vehicles, equipment, etc.), transport infrastructure facilities (buildings, stations, bridges, railways, repair depots, etc.), as well as links between all these objects.

IST design is carried out at various levels of abstraction (detailed reflection of elements, properties, characteristics, etc.). Such structure can be implemented with varying degrees of detail, depending on the characteristics of the design tasks.

The creation of formal system that describes the behavior of controlled complex dynamic object (which is IST) is carried out on the basis of conceptual model of the essential properties of studied SA, which determines construction of dynamic knowledge base of IS and provides the possibility of formal and rigorous definition of concepts and patterns of natural classification.

Conceptual model of ontology. The system that describes the knowledge base during the functioning of IST in real time contains elements that provide ontology modification based on standard procedures of complex ontology and meta-ontology. Building conceptual model of IST ontology involves the following steps:

1. Formalization of complex ontology:
   Modernization of the classical model.
   Modernization based on the system concept.
2. Formalization of meta-ontology:
   Model based on the concept of the system.
   Model based on formal theory.
3. Formalization of theoretical models of knowledge engineering:
   Model "Field of knowledge".
   Model "Pyramid of knowledge".
4. Formalization of ontology axioms:
   Axioms of identification.
   Axioms of planning.
   Axioms of computation.

Objects in this ontological model are systematized according to the functional feature of their properties, which are part of the class hierarchy. *Links* determine the structure of system, and *elements* determine the function of nodes in this structure. Structure can be refined into more detailed descriptions of specific classes of model objects by separating properties (at each level of model).

The considered classification can be refined (renamed, extended, supplemented by derived classes) depending on the task of information processing and changes in knowledge about IST. For example, class INFORMATION STRUCTURE in property classification can be refined by highlighting the properties STRUCTURE BY MANAGEMENT and STRUCTURE BY DATA. This will entail allocation in classification of components within the class INFORMATION COMMUNICATION of subclasses of communications COMMAND TRANSMISSION and DATA TRANSMISSION, which can be assigned appropriate designations.

When formalizing the task of building ontology knowledge base, the interpreted characteristics of the system improve and simplify its use for managing IST (including its design and maintenance), especially in emergency and extreme situations.

The ontology model used describes the computer interpretation (construction of formal system models) of SA related to the formalization of the task of monitoring the functioning of IST and modeling emergency and extreme situations that arise during operation.

Ontological model of SA. The development and formalization of complex ontology when creating design and maintenance management system IST involves formal representation based on the conceptualization of knowledge of SA model, which describes set of objects and concepts, knowledge about them and relationships between them.

Subject area D_{SA} is part of reality to be reflected on the basis of intelligent technologies in order to obtain new information about its properties. D_{SA} is interpreted as part of the real world that has semantic localization (spatial, temporal, functional, etc.).

Considering the *semantic space* of studied SD_{SA}, it is necessary to perform semantic localization of its subdomains SD_{SA_i} (i=1, …, n). $SD_{SA} = \{SD_{SA_1}, \dots, SD_{SA_i}, \dots, SD_{SA_n}\}$.

Semantic localization in IST is associated with definition of the boundaries of individual D_{SA} subdomains (SD_{SA_i}) in SD_{SA} semantic space that encompasses them. At the stage of knowledge formalization, the components of subdomains included in SA D_{SA} can be considered as set P of their semantic properties P_{ij}:

$OM_{SD_{SA1}} = \{P_{11}, P_{12}, \dots, P_{1m}\}, \dots, OM_{SD_{SAn}} = \{P_{n1}, P_{n2}, \dots, P_{nm}\}$.

In this case, there is intersection of sets of semantic properties of different SD_{SA_i}

$OM_{SD_{SA1}} \cap \dots \cap OM_{SD_{SAi}} \cap \dots \cap OM_{SD_{SAn}} \neq \{0\}$.

Which allows us to write down the criterion for the localization of D_{SA} in semantic space

$OM_{SD_{SA1}} \cap \dots \cap OM_{SD_{SAi}} \cap \dots \cap OM_{SD_{SAn}} = \{0\}$.

Necessary criterion for the existence of SA D_{SA} is the distinguishability of its properties in presented semantic localization. For the set of properties P of model of SA D_{SA} under study, its unique identification follows. At the same time, the properties remain identical to themselves for time that is sufficient to construct SA D_{SA} model and use it in IST knowledge system.

When modeling IST processes, *functional completeness* and *logical integrity* of model are of great importance. The functional completeness of SA D_{SA} model does not imply the most complete reflection of the properties of objects, but only the fixation of those properties that are necessary and sufficient for solving the tasks of IST management (including its design and maintenance).

The criterion for the functional completeness of the SA model depends on the class of tasks being solved and requires the determination of the criterion for the depth of detail SA. The formal statement of problems allows us to highlight the features of the current situation, the modeling of which is necessary and sufficient for choosing solutions for the design and maintenance of IST.

The complex ontology that is used in the development of the IST management system (in particular, its design and maintenance) can be based on various formalizations.

Formalization of the ontology of SA. The conceptual foundations for formalizing ontologies of various SA were considered in [14, 17, 18]. In [14, the allocation of classes of terms, relations and transformations corresponding to physical and abstract entities for solving SA problems (in our case, in transport) is described.

The SA representation serves as signature for the development of subject knowledge model. Let us define ontology of SA D_{SA} as:

$Ont(D_{SA})_S = <T(S), R(S), Ax(S)>$,

where *S* (Subject) is set of SA D_{SA} objects, *T(S)* is finite set of classes of terms (concepts) of SA D_{SA} that have features that make up their distinctive feature in ontology; *R(S)* – finite set of relations between term classes; *Ax(S)* is finite set of axioms (functions, interpretations) defined on ontology classes and relations.

A natural constraint imposed on the sets *T(S)*, *R(S)*, and *Ax(S)* is their finiteness and non-emptiness. The elimination of the emptiness of the sets *R(S)* and *Ax(S)* makes it possible to use hierarchical system of concepts interconnected by various relationships.

Concepts are organized in hierarchies, the links within which are structured in such way as to carry out logical conclusion based on the transition from the general to the particular and vice versa.

Theoretical aspects of "knowledge engineering" when interpreting the behavior of complex object (technical, transport, intellectual, etc.): determine the basis for the formation of dynamic models "field of knowledge" and " pyramid of knowledge "; require clarification; should be focused on strategies for presenting and interpreting information in complex systems.

Let's consider these questions on the examples of complex ontology implementation when building the " field of knowledge " and "pyramid of knowledge " models.

The "field of knowledge" model is informal description of the main concepts and relationships between them, identified from the knowledge system of the studied SA. The formation of the "field of knowledge" is carried out at the stage of structuring and is the first step towards the formalization of knowledge. When designing and maintaining IST, the “field of knowledge” model should be considered as complex dynamic structure.

One of the directions for the implementation of modern trends in the construction of the "field of knowledge" model is associated with the concept of *ontological engineering* − one of the approaches to the semiotic modeling of SA [19].

The semiotic model of the “field of knowledge” of SA D_{SA} can be represented as follows:

$SM_{D_{SA}} = <Sin, Sem, Pr>$,

where *Sin* is the syntax; *Sem* is the semantics; *Pr* is the pragmatics.

The operational model of SA D_{SA} within the framework of the semantic structure is represented as:

$OM_{D_{SA}} = <Sc, Sf>$,

where *Sc* is the conceptual structure; *Sf* is functional structure.

The “field of knowledge” model is being improved on the basis of applied semiotics methods within the framework of the situational management approach [20]. The implementation of the approach to the formalization of the "field of knowledge" based on semiotic modeling opens up new possibilities for using complex ontology in formalizing the knowledge of complex systems.

The “pyramid of knowledge” model can be represented by the following interpretation:

$$F: Pkn \rightarrow Pkn^*,$$

where $Pkn = (S, T, R, St)$; $Pkn^* = (S, T^*, R^*, St^*)$; *S* is the set of SA objects; T^* – meta-concepts of higher level of abstraction than *T*; R^* – meta-relations; St^* are meta-strategies.

An example of implementation of "pyramid of knowledge" is the interpretation of procedural component of IST knowledge base. The implementation of information transformation mechanisms in the “pyramid of knowledge” model depends on the complexity of current situation and is determined by different functional structures. One example of such structure is information flow when choosing the preferred solution in the IST process management system (including design and maintenance).

Ontological approach to IST design. The application of the ontological approach simplifies the process of optimal design, allows solving the main tasks of modern design at various stages of creating IST, and coordinating the parallel work of IST developers and the IST management system.

IST process management is process that includes, in particular, following steps:

Preparation of terms of reference for the development of IST and its monitoring.

Development of the SA model (with precise definition of the SA objects, their characteristics, properties and relationships), its verification and testing.

Development of IST architecture.

Development of the IST information base structure (knowledge base, database, ontology, meta-ontology, etc.) and its dynamic modification.

When implementing these stages, the technology of parallel design is used, which provides direct and feedback connection between the current and previous stages. When designing IST, it is advisable to use the decomposition method. Based on the basic principles of IST optimal design, knowledge-oriented information technologies are introduced into the design process using the example of applying the concept of ontological knowledge bases.

Ontological knowledge bases contribute to the presentation of design process data in the form of structure with clearly defined relationships between the various components of the process, the integration of various design data, and the organization of links between various stages and design tasks. By formal ontological model we mean triple:

$$O_M = <S, R, Fun>,$$

where *S* is finite set of SA objects; *R* is finite set of relations between the SA objects; *Fun* is finite set of functions (interpretations) defined on objects. Consider the IST design ontology, which contains the concepts of SA, the interpretation of knowledge and relationships within this area.

Let us describe the ontological approach in the form of the following algorithm of actions:

1) compiling dictionary based on the terminology of SA for which IST is being designed;
2) using dictionary, obtaining ontology of SA that reflects the relationships between concepts;
3) verification by experts of the created ontology of SA, support and filling of the ontology.

The thesaurus of SA can be used as tool for standardization and formalization of knowledge, as well as for providing access to users who solve IST process management tasks (including design and maintenance).

Thesaurus of SA is designed to solve the following tasks:

classification and unification of the concepts of SA;

classification of methods and tasks of IST design;

construction of descriptions of methods and tasks of IST design in knowledge bases.

The IST process management ontology (including design and maintenance) uses thesaurus and is required to:

develop and fix common understanding of the area of knowledge under consideration;

present knowledge in form that is convenient for their processing in IST;

provide opportunity to obtain and accumulate new knowledge;

provide the possibility of reuse of knowledge (including reuse of ontologies).

To represent the IST design ontology, the ontology description language OWL (Ontology Web Language) [21] was chosen, which consists of the following components: classes, class properties, and individuals (representatives of classes or properties). The construction of the IST ontology is performed in the ontology editor Protégé [22].

The developed ontological model is represented as an ontograph. Protégé allows you to formally check the ontological model (in particular, check for the absence of errors, the presence of all necessary links and dependencies within the ontology).

Conclusions. The complex ontology used in IST is defined as semantically-oriented information environment of conceptual generalization, which provides the possibility of integrating knowledge while formalizing current information.

The main advantages of using the proposed ontological approach to managing IST processes, in particular, are:

compact representation of the knowledge system of SA (specification and conceptualization);

the possibility of searching for information in the knowledge system of the obtained ontology (obtaining reference and training information);

setting and solving the necessary applied tasks within the framework of SA (for example, tasks of design and maintenance IST);

possibility of gaining new knowledge and development of IST (management system of IST);

the possibility of using modern multi-agent technology, when each agent has its own ontological model.

The proposed ontological approach to IST control (management) allows moving to automatic process control (if there are appropriate restrictions). In the absence of restrictions, but in the presence of ontological models of individual agents, automated control is used.

The developed ontology of SA is planned to be expanded and supplemented with new components, imposing appropriate restrictions.

The program code in OWL obtained from the simulation results in Protégé can be further used inside the knowledge base, processing this information in various software applications, including Java applications.

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МОДЕЛЮВАННЯ УПРАВЛІННЯ ІНТЕЛЕКТУАЛЬНІМИ СИСТЕМАМИ НА ТРАНСПОРТІ

У статті розглядаються актуальні проблеми моделювання процесів управління в інтелектуальних системах на транспорті. Управління такими системами передбачає також контроль і моніторінг процесів їхнього проектування та супроводження. В статті запропоновано онтологічну модель управління процесами інтелектуальних систем на транспорті. Запропонована онтологічна модель необхідна для формування загального розуміння сутностей предметної області, якою є транспортна сфера (транспортні системи, транспортні підприємства, транспортні засоби та транспортна інфраструктура). Запропонована онтологічна модель сприяє представленню знань у вигляді, який є зручним для їхньої обробки в інтелектуальній системі на транспорті; забезпеченню можливості отримання та накопичення нових знань.

У запропонованому онтологічному підході забезпечується багаторазове використання знань та, раніше розроблених, онтологій. Запропонований підхід дозволяє використовувати сучасну мультиагентну технологію, коли кожному агенту відповідає своя онтологічна модель. Розглянутий онтологічний підхід до моделювання управління інтелектуальними системами дозволяє перейти до автоматичного управління процесами в цих системах (за наявності відповідних обмежень).

Розроблену онтологiіну модель предметної галузі планується розширити та доповнити новими складовими, наклавши відповідні обмеження. Отриманий за результатами моделювання в Protégé програмний код OWL можна надалі використовувати всередині бази знань інтелектуальної системи, обробляючи цю інформацію в різних програмних застосунках, в тому числі, і Java-застосунках.

Ключові слова: *управління, проєктування, інтелектуальна система, мультиагентна технологія, інформаційні ресурси, база знань, моделювання, онтологіна модель.*