Basic Priciples of the Ontology of the Transportation Process in Railway Transport

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***Abstract*—The relevance of developing an ontology for an intelligent transportation process management system is determined. The structure of the theory of ontology construction is given. The existing ontologies of railway systems are described. The problems of existing ontologies are established. It is proposed to use a process-object approach in the formation of ontology. Examples of the use of ontology are given. Indicated that the OSTIS technology is an effective tool for describing the process-object ontology of the transportation process.**

***Keywords*—Intelligent transportation process management system, ontology, knowledge base, process-object approach, OSTIS technology**

I. Introduction

Digitalization of technological processes is one of the most effective ways to improve the efficiency of both individual enterprises and entire industries. This fully applies to railway transport.

For these purposes, the Belarusian Railway has implemented a number of projects on the informatization of key technological processes. The Information and Analytical Management Decision Support System for Freight Transportation (IAMDSS FT) provides specialists and managers at all levels with prompt and reliable information about freight transportation that are being performed and were performed, the condition and location of the wagon and locomotive fleets. The Unified Corporate Integrated Financial and Resource Management System (UC IFRMS) based on SAP SE products is designed for effective information support of planning, modeling and operational management of financial and economic activities of the BR divisions.

The creation of the Transportation Management Center and its equipping with automated dispatch control systems using "Neman" software and hardware has been completed, the development of train schedules using "Grafist" automated control systems has been automated, and separate planning procedures have been automated. At the line level, there are automated management systems for stations and linear areas (AMSS, AMSLA), a system for automating the preparation and processing of station and commercial reporting documents (SAPPD).

The implementation of the above-mentioned and a number of other systems made it possible to create a fairly detailed and complete database on the transportation process and the railway as a whole. At the same time, information technologies operating in railway transport make it possible to implement only certain functions of the management cycle, entrusting the procedures for forming, evaluating and making managerial decisions (MD) entirely to a human.

The greatest problems arise with significant deviations from pre-developed technologies (delay of a passenger train, shortage of capacity of the station's fleet, lack of empty wagons for loading, etc.). It is at those moments, when a person needs help in making managerial decisions, that modern automated systems are not effective enough. In such conditions, a person, as a rule, when searching for rational MD, resorts to his experience based on partially unformalized knowledge and empirical experience, and to a lesser extent relies on the help of information systems.

Next logical stage in the development of information technologies in railway transport is the transition from information and reference systems to information and analytical and information management systems. In this regard, as foundation for the digital transformation of railway transport is proposed to consider an intelligent transportation process management system (ITPMS).

The development of the ITPMS presupposes the existence of unified ways to describe the system and the processes occurring in it — ontologies. [1]

II. The concept and basis of ontology

The use of a single "metaplatform" contributes to the improvement of transport processes, simplification of document flow and acceleration of information exchange between participants in multimodal transportation. This approach leads to a synergistic effect on three levels: within each mode of transport, between different modes of transport and in the transport complex as a whole.

However, the development of such systems faces a huge amount of information that needs to be integrated and coordinated within a single digital platform. Data sources are often disparate even within a single company, and the information contained in them can be duplicated, diverse, and have complex relationships such as synonymy and mero-holonymy. The complexity of the task increases exponentially when scaled to the level of the entire transport system or the transport complex as a whole.

In the field of multimodal transportation, the active use of knowledge brings significant benefits to all participants. For example, successful innovative solutions that were once used and accelerated the movement of goods in the logistics chain or brought additional profits are becoming available to everyone. The ability to generate new knowledge can help to find such solutions, even if they have not been used before. Ontologies, as well as frame models of knowledge representation, are the basis of such solutions [2].

Ontologies can be classified into four levels depending on their goals:

1) Representation Ontology: They define the domain of knowledge representation and serve as the basis for creating a specification language for lower-level ontologies.
2) Top-level Ontologies: They describe abstract interdisciplinary concepts and the connections between them. Such ontologies capture general knowledge applicable in several subject areas.
3) Domain Ontology: They describe and summarize concepts specific to a particular subject area.
4) Applied Ontologies: They describe the conceptual model of a specific task or application.

The following approaches are distinguished within these levels:

- Formal taxonomies: They define a "class-subclass" relationship and ensure the transitivity of this relationship.
- Formal instances: They define a "class-instance" relationship and add instances to the class hierarchy.
- Disjunctive classes, inverse properties: They allow you to declare two classes disjoint and allow you to make not only direct inference, but also reverse.
- Ontologies with restrictions on the scope of property values: Property values are selected from a predefined set or subset of concepts.
- Frame-based properties: Each class can also have slots containing information about its properties, also they can be inherited by classes of higher levels.
- Arbitrary logical constraints: Allow you to define arbitrary axioms.

Ontologies can also be classified by content into:

- General Ontologies: They describe the most general concepts, independent of specific problems or areas.
- Task ontologies: They reflect the specifics of particular applications, tasks or programs.
- Subject ontologies: They describe real objects used in a certain activity.

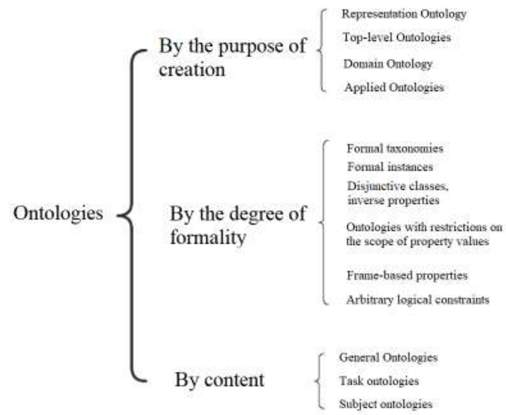

Figure 1. Ontology classification

According to Gruber's definition [4], an ontology is an explicit specification of a conceptualization, a formalized representation of concepts and the connections between them. Formally, it has the form

$< C, R, P, A >$,

where

C is a set of concepts of a specific subject area,
R is the set of relations between concepts,
P is the set of attributes of concepts,
A is a set of axioms.

III. Current state of ontologies in railway transportation

The process of creating ontologies is complex and nontrivial. When developing them, as a rule, experts from different fields are involved (in the subject area, linguists, programmers, etc.), each of whom applies their own methods of work. But there are still no universal methods, and the correctness of the result obtained is determined specifically for each particular task. [5], [6] Ontological analysis determines the functional structure (connections between objects) and determines the behavior of the system (scenarios).

The existing IDEF5 [3] standard describes the construction of ontologies in a very simplified way. Due to the lack of a theoretical methodology for determining the structure of information, the task of finding the fundamental foundations for creating a developed transport ontology is urgent.

At the moment, ontologies are used in intelligent railway transport management systems (IRTMS) both in JSC "Russian Railways" and on the railways of the European Union. However, the analysis of these ontologies shows that they are rather intended for storing and consolidating data on the state of various objects of the transportation process. They are applied and are not currently focused on expanding to the entire subject area.

The ontologies used on the railways of the European Union are even more narrowly oriented and do not include the more abstract, technological level of knowledge that is present in the ontologies of this field. One of the reasons for the inapplicability of Western ontologies is the structural difference of the railway system. The terminology sets describing the Belarusian Railway and European railways differ significantly. Despite the presence of common concepts at a high level, such as "Station" and "Wagon", at lower levels, such as classification of wagons, tracks, document management and others, the terms are fundamentally different.

Nevertheless, the ontology being formed should be interdisciplinary, since various modes of transport with their own technology and specifics of work, regulatory documents, loading and unloading regulations, etc. participate in transportation. To ensure internal consistency of ontologies, it is necessary to determine a common "point" around which they can be combined. In this case, such a unifying "point" may be cargo, and then the subject area will be "cargo transportation".

Thus, the use of foreign ontologies is not possible, and in the case of integration with European systems, the ontology will have to contain universal concepts describing those concepts in a form understandable to both sides.

It should also be noted that the railway infrastructure is a strategically important facility. Thus, this area should be import-independent. And one of the problems of the existing ontology used in IRTMS is the dependence on Western instruments.

Despite the fact that, at first glance, it is sufficient to consider the ITPMS as an ontology of the subject area, it must be borne in mind that the ITPMS is the first stage in building an Intelligent Transport Management System and must have all the features of top-level ontologies. This task is inextricably linked with the formation of a digital model of the transportation process (DMTP). The current mechanisms for the formation of the DMTP should allow for online modeling of the state of the transportation process. This requires the unification of requirements for the content and form of presentation of information about the parameters of the functioning of objects. DMTP may include:

- models of objects (including resources);
- process models — description of processes occurring both in the ITPMS and in the external object environment;
- models of the external object environment describing the external impact on the objects of the transportation process;
- models of predicting situations — study of options for the development of the transport situation with abnormal changes in the state of elements of the transport system, the external environment, with changes in the characteristics of information flows;
- models for the formation of managerial decisions that provide an analysis of the operational situation and the formation of effective managerial decision;
- evaluation models that provide an assessment of the effectiveness of implemented MD, the condition of facilities and the parameters of the transportation process.

The basis for the formation of the ontology under consideration can be the subsystem of the normative-reference information of IAMDSS FT (SNRI). This subsystem contains many tables describing both static and dynamic objects. However, in its pure form, SNRI does not allow solving operational tasks, but is used only as reference information. Thus, the scientific problem of developing tools for the transformation of normative-reference information into an ontological description of both the subject area and interdisciplinary concepts should be solved.

IV. Our proposal on the direction of research in the field of development of railway transport ontology.

In our work we propose to use the OSTIS technology and platform, which is being developed in the Republic of Belarus. Within the framework of this technology, tools for creating ontologies are implemented, as well as creating agents to work with it. [7]–[10]

Based on the above justifications of relevance, the following tasks can be distinguished for ontology:

- Fully describe the objects and processes of the transportation process.
- Converting information from existing standards to a knowledge base and back.
- Set of agents for data transformation.
- Storage and analysis of external information.
- Storage of managing decision models.
- Set of agents for converting incoming information into a managing decision.

Accordingly, the Knowledge Base can be divided into subdomains.

1) Description of the main objects involved in the transportation process;
2) Description of the processes occurring in the ITPMS, as well as external processes affecting the ITPMS;
3) Description of external objects that affect the transportation process;
4) Description of possible emergency situations, models for predicting their development;
5) Description of possible managing decisions;
6) Description of criteria for evaluating managing decisions and the result of their impact on the system.

Some examples of subject areas that can be included in the ontology of the transportation process:

1) Railway lines and stations: This subject area describes information about various railway lines, including their geographical location, length, speed limits, track types, and accessibility. It also includes information about stations, including their location, capacity, and cargo and passenger handling capabilities.
2) Cargoes and containers: This subject area describes various types of cargoes and containers, their characteristics (weight, volume, type of packaging), processing and storage requirements. It also includes information about special requirements for certain types of goods, for example, goods requiring special transportation conditions (temperature conditions, vibration protection, etc.).
3) Schedule and Train Timetable: This subject area describes information about the train timetable, including departure and arrival times, intermediate stops, travel speeds and possible overlaps on the track. It also includes information about the regularity and repeatability of the train schedule.
4) Resources: This subject area describes information about available resources such as locomotives, wagons, personnel, and technical equipment. It includes the characteristics of resources (load capacity, technical parameters), their availability and maintenance schedule.
5) Laws and Regulations: This subject area describes the laws, rules and regulations governing railway logistics. It includes safety rules, standards for the transportation of certain goods, requirements for staff working hours, rules for the priority of train traffic and other regulatory information.
6) Monitoring and Data collection: This subject area describes the monitoring and data collection systems used to obtain information about the current state of railway logistics. It includes data on train movement, cargo status, information about delays and other factors affecting planning and management.

Various problem solvers can be used to automate transportation planning and management. Here are some typical problem solvers that can be applied in this field:

1) The routing problem solver: This solver allows you to optimize train routes, taking into account various factors such as schedules, availability of railway lines, cargo requirements and restrictions on infrastructure and transportation conditions. It helps to choose the best routes, minimizing the time and cost of transportation.
2) Train timetable development solver: This solver allows to optimize the train timetable, taking into account the timetable, passenger and cargo requirements, infrastructure constraints and other factors. It helps to allocate trains by time and resources, ensuring efficient use of the railway network.
3) Loading planning problem solver: This solver helps to optimize the loading of wagons, taking into account the characteristics of goods and limitations of wagons, such as load capacity, dimensions and special requirements. It helps to maximize the loading of wagons, minimizing empty runs and improving the use of the wagon fleet.
4) The solver of the optimal resource planning problem: This solver allows you to optimize the allocation of resources such as locomotives, wagons, personnel and technical equipment to ensure the efficient operation of the railway system. It takes into account transportation requirements, traffic schedules and resource constraints, helping to achieve optimal use of resources and reduce costs.
5) Demand Forecasting and Planning Solver: This solver is used to predict the demand for rail transportation, taking into account various external factors such as economic conditions, seasonality, trends and others. It helps to plan capacity and resources to meet demand and prevent congestion or lack of transportation capacity.
6) Monitoring and Management Problem Solver: This solver is used for continuous monitoring and management of railway transportation. It analyzes data on train movements, traffic status, delays and other events, allowing you to make operational decisions and respond to changes in real time.

These are just some examples of problem solvers that can be used to automate the planning and management of railway logistics. The specific set of solvers will depend on the specific requirements and characteristics of the railway logistics system, as well as on the goals and constraints set.

Using ontology for these problem solvers in the field of railway logistics can bring several advantages:

1) Knowledge structuring: Ontology allows you to structure knowledge about the main subject areas of railway logistics, such as infrastructure, resources, cargo and schedules. This facilitates the understanding and organization of information, simplifies its accessibility and exchange between different systems and participants.
2) Data unification and standardization: An ontology defines common semantics and standards for data representation in railway logistics. This allows different systems and applications to use the same terms and data formats, which ensures consistency and compatibility of information. This is especially important when integrating different systems and exchanging data between them.
3) Improvement of planning and optimization: Ontology provides a formalized domain model on the basis of which planning and optimization algorithms

can be developed. The use of ontology makes it possible to take into account various limitations, requirements and dependencies between different aspects of railway logistics. This contributes to more efficient use of resources, route optimization and improved service quality.

4) Decision Making Improvement: Ontology can be used in decision support systems, providing a semantic model and context for data analysis and recommendation generation. It allows systems to identify dependencies and relationships between various factors, to carry out forecasting and scenario analysis, which helps to make reasonable and informed decisions.
5) Ease of expansion and modification: Ontology provides a flexible and extensible domain model that can be easily modified and supplemented as needed. This allows you to adapt the ontology t new requirements, changing conditions and expar its functionality. This flexibility makes it easier t support different types of tasks and to develop tl system in the future.

In general, the use of ontology for data solvers in tl field of railway logistics contributes to improving da organization, information compatibility and consistenc optimizing planning and management processes, as we as making informed decisions based on data analysis.

The ontology for these problem solvers in the fie of transportation process management should be flexib and modular in order to take into account various facto and adapt to changing conditions.

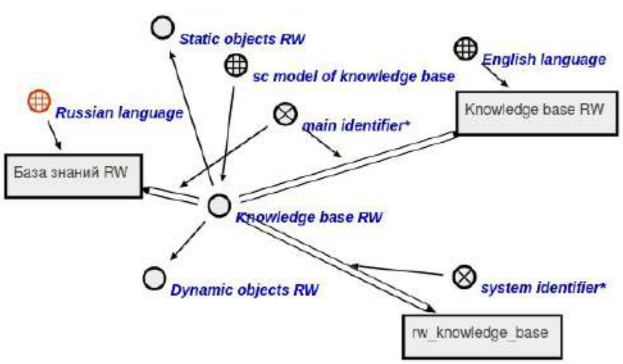

Figure 2. Semantic neighborhood of knowlegebase RW

Within the framework of this work, a top-level ontology is implemented describing the main objects of the transportation process, examples of objects of which are presented in Figures 2-4 in the form of an SCg code [10].

V. Conclusion

Thus, within the framework of this work, the relevance of developing an ontology for an intelligent transportation process management system has been determined.

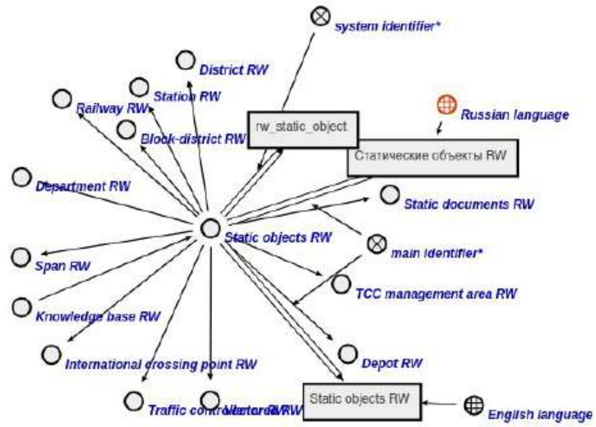

Figure 3. Semantic neighborhood of static objects RW

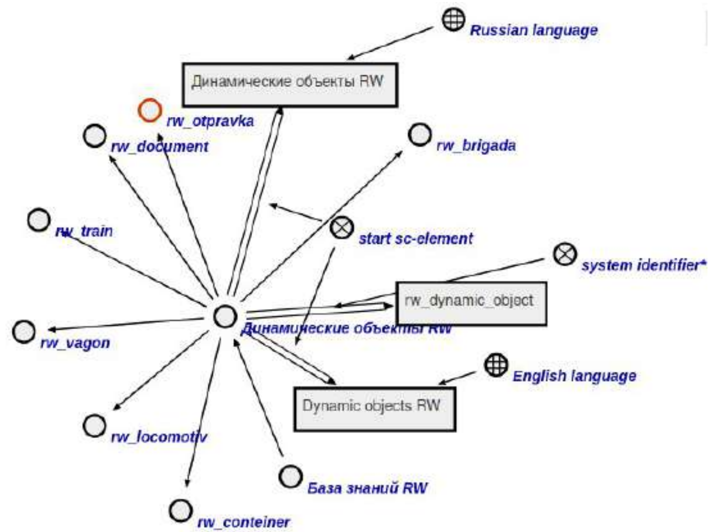

Figure 4. Semantic neighborhood of dynamic objects RW

The structure of the theory of ontology construction is given. The existing ontologies of railway systems are described. The problems of existing ontologies are established. It is proposed to use a process-object approach in the formation of ontology. Examples of the use of ontology are given. It is indicated that the OSTIS technology is an effective tool for describing the process-object ontology of the transportation process. The top-level ontology for the Belarusian Railway has been implemented.

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ОСНОВЫ ОНТОЛОГИИ ПЕРЕВОЗОЧНОГО ПРОЦЕССА НА ЖЕЛЕЗНОДОРОЖНОМ ТРАНСПОРТЕ

Ерофеев А. А., Ерофеев И. А.

Определена актуальность разработки онтологии для интеллектуальной системы управления перевозочным процессом. Приведена структура теории построения онтологии. Описаны существующие онтологии железнодорожных систем. Установлены проблемы существующих онтологий. Предложено при формировании онтологии использовать процессно-объектный подход. Приведены примеры использования онтологии. Указано, что эффективным инструментом описания процессно-объектной онтологии перевозочного процесса является технология OSTIS.

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