Pattern Model Stratification to Decision-making Support of Transport Infrastructure Management

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Abstract: Design and engineering of patterns requires tools to enable these processes by means of universal creation and dynamic modification of objects. The article introduces the basic definitions of pattern design (hereinafter P-models), specifies the types and structures of patterns, determines the organization of object design based on P-models. The *introduced* axiomatic and systematization are based on the use of original definitions and form the concept of stratified pattern construction of objects and associations. A stratified pattern model is considered as an information, methodological and implementation basis for the design of the decision support system of transport infrastructure management. The synthesis of the decision support system of transport infrastructure management is made on the fundamental methodological basis, determined by the object-oriented paradigm. The synthesis of universal structures based on patterns is considered on the formal declaration of objects invariant to their subject orientation. Along with the synthesis of methodical P-models, the patterns of formalization and systematization of relevant information-logical and functional aspects of transport infrastructure are described. The implementation P-models contains the effectiveness of the pattern design of the decision support system of transport infrastructure management of the processes of modelling, management, experimental studies.

1 INTRODUCTION

The system approach, as a scientific direction of solving management problems, is the study of objects and systems with the analysis of static structures and dynamic functionals. The system is aggregated by a set of components that are in a relationship, having connections between themselves, forming integrity and unity (Kabir et al., 2018). A complex organizational and technical decision support system for transport infrastructure management is a system that emphasizes the cognitive and adaptive aspects of its operation, which has the potential for self-organization and development (Šelih et al., 2008; Speranza, 2018). Attempts to formalize decision-making support tasks have led to the emergence of a number of approaches, methods, and intelligent systems that help the decision maker in his work.

In all engineering disciplines, object-oriented analysis, design, and programming, based on the principles of decomposition, abstraction, and hierarchy, are widely used (Coad and Yourdon, 1991). Modern methodologies of structural analysis and design in CASE-tools, various knowledge engineering technologies in general do not offer a systematic procedure or formalism allowing to “deduce” the structure of concepts and relations of the subject area from the data available about it (Golovnin and Mikheeva, 2018).

2 PATTERN STRATIFICATION

The methodology of formalizing, analysing, and synthesizing a decision support system of transport infrastructure management is based on an integrated strategy for increasing the level of abstraction of the models used, covering the realizable combinations of

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features of domain objects. The methodology is based on the concept of object-oriented analysis and design as a set of entities of the domain (objects) interacting with each other, considering objects as instances of certain classes that form the taxonomic hierarchy (Cai et al, 2018).

Implementing projects to develop decision support systems and business process modelling creates situations where problem solving in various projects has similar structural features. In many object-oriented systems, you can find patterns consisting of classes and interacting objects, with the help of which you can solve specific design problems that exist simultaneously in several systems. The generalization and classification of such tasks and the most successful ways to solve them led to the emergence of patterns. The pattern approach is characterized as any mathematical theory is a set of special cases that are interpreted from a unified position (Grenander, 1993). On the basis of object-oriented design, the pattern from an abstract category has become an integral attribute of modern CASE-tools (Limayem, 2004; Maksimov et al., 2018).

The essential features of the intelligent transport geographic information system for decision-making, as an informational pattern model, are:

- the complexity and scale of the models that fill the transport infrastructure management system, expressed in a large number of types, using alternative mechanisms of multiple inheritance and polymorphic redefinition of object types properties, using nested aggregate and selective constructions and associations (Petzold and Freund, 1990; Vanier, 2004);
- the need to support queries to data in declarative, predicative and navigation styles, the effective implementation of basic manipulating operations (Tomingas et al., 2015);
- wide context of using models in applications that operate with data from one multidisciplinary information scheme, as well as data from several independent schemes (Kleppmann, 2017);
- interaction with external systems, heterogeneous, hybrid, multifunctional with the definition of the mechanism of interaction, integration into a single space of data and functional (Wood et al., 2015).

Definition 1. A pattern is a sample, a template model, a formalized description of a frequently encountered design problem; an effective in a given context typical solution of a design (software) problem. We define a pattern model as a P-model.

In modern software engineering, the creation of software products relies on the explication of the intellectual role of software and hardware concepts. In this sense, the architecture of the transport infrastructure management system should include structural and functional components that, individually or in certain combinations, are designed to display the intelligent units of the overall design scheme and the technological components with which the intelligent units in question are generated and interconnected.

According to the dominant cognitive paradigm for abstracting any subject area, the categories of “objects” and relations between objects are recognized as primary and atomic.

The declaration of generalized properties inherent in objects of the domain, and the generalization of these properties to ensure the transition to the highest level of the abstraction hierarchy, are inherent in taxonomic object-oriented models. This abstraction provides a modular (patterned) system design due to a stratified rise from one level of the generalization hierarchy to another.

It is reasonable to use object-oriented taxonomic models as a methodological and informational basis for designing a decision support system for managing transport infrastructure. Unlike network, relational, and hierarchical models, which declare only static relationships, taxonomic models not only structure information, but also ensure the “inheritance” of both the class objects themselves and the processing methods of object-oriented structures; the entire inheritance hierarchy, which allows to synthesize patterns.

Thus, taxonomy with stratification functional is most relevant to the tasks of developing a transport infrastructure management system.

Definition 2. The stratified P-model declares the static regulation of the structured construction of classes of objects and interclass relations.

The stratified P-model declares strata as objects that receive ontological meaning and describe elements of a nonlinear-dynamic system, which is the decision support system of transport infrastructure management. Interclass relations specified by the P-model cannot be changed in the dynamics of the simulation process. Static character of the regulations does not mean the static nature of the objects constructed under this regulation, they can be dynamically reconstructed in accordance with the structure of interclass relations in the model.

Visually, the P-model is represented by a set of nested spherical strata defined by a triad $\left\langle \widehat{S},\ (\Psi_1,\Psi_2,\ ...,\ \Psi_n),\ \Omega \right\rangle$, where $\widehat{S}$ is the set of strata of the domain space, $\Psi_1,\Psi_2,\ ...,\ \Psi_n$

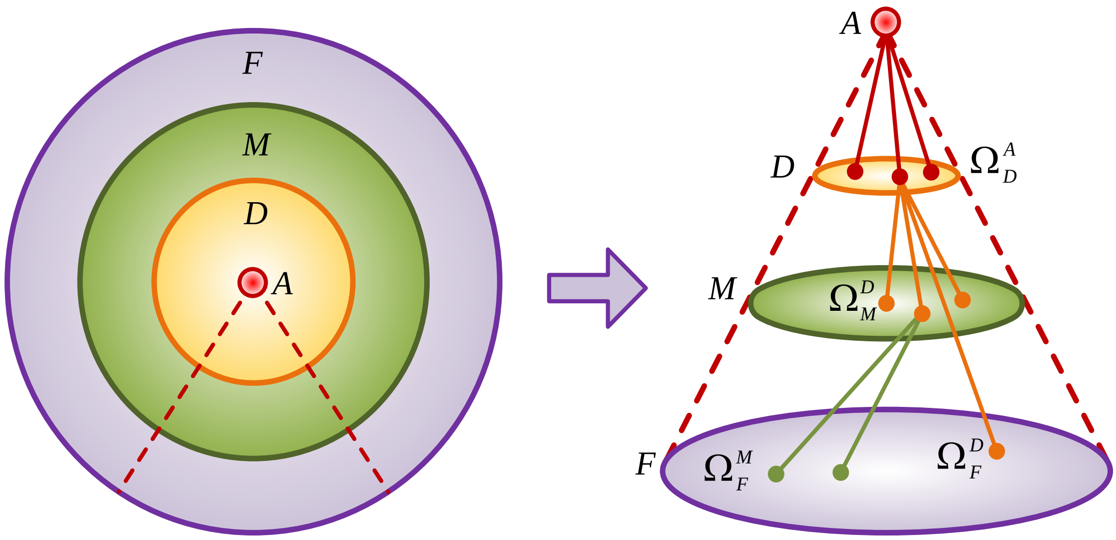

Figure 1: Stratified P-model.

is the set of types of relations (connections) between the strata of the space, Ω is the set of mappings. In addition to traditional spatial, temporal and causal relations, the system also contains specialized relations characteristic of the subject area: set-theoretic, logical, functional, topological, hierarchical.

The spherical stratum is a class of objects and can be decomposed to obtain the necessary level of detail. Decomposition is represented by clipping a cone from the common domain space (Figure 1). We define mappings from any stratum to each, which allows us to link data from different strata. At the same time, it is necessary to ensure the preservation of strata invariants — the set of essential and invariable properties of the objects of each strata.

The stratified P-model of the decision-making support system of transport infrastructure management is defined as the tetrad of strata: $P(\widehat{S}) = \{A, D, M, F\}$.

The central stratum of space is filled with basic atomic patterns that have the indivisibility of their semantics and functionality. In accordance with the stratification methodology, the following strata are defined as: declarative stratum, methodical stratum and implementing (functional) stratum.

The declarative stratum is stratified into strata of information about the objects of the subject area, their immanent properties and architectural structures. The knowledge representation stratum contains statically declared data models and output algorithms that operate on data structures and have a functional independent of the content.

Methodical stratum is stratified into strata of methods for collecting, processing, storing, transmitting information about domain objects, mathematical methods of intellectual analysis, design, modelling, visualization, prediction of situations arising.

The implementation stratum is stratified into the strata of the data processing software of the declarative stratum through the program implementation of the methodical stratum methods based on functional zoning patterns.

Stratum mapping is defined as: $\Omega_D^A : A \to D$, $\Omega_M^D : D \to M$, $\Omega_F^D : D \to F$, $\Omega_F^M : M \to F$.

The synthesis of universal structures based on patterns is based on the formal declaration of objects that is invariant to their subject orientation. Such an approach to the development of a complexly organized decision support system is provided by the pattern representation of any object of transport infrastructure in the form of an architecture consisting of two parts: the formal (architectural), interaction with which is carried out only through universal declarative patterns, and the content filled with the values of the intrinsic domain objects.

Along with the synthesis of methodical P-models, patterns of formalization and systematization of relevant information, logical and functional aspects of transport infrastructure are defined, patterns of formal transformation of initial information into pattern specification that implements all key forms of semantic abstraction, modelling, zonal management and analysis of transport infrastructure based on artificial intelligence.

Implementing P-models contain the effectiveness of the pattern design of the decision support system of transport infrastructure management of the modelling, management, and experimental research processes. This gives a qualitative explanation of the main phenomenon of the conceptualization phase in the tasks of constructing complexly organized systems — the possibility of the formation and coexistence of various types of models within one subject area.

Synergetic P-models act as part of a system analysis of the general principles of the complex system, which is considered as a decision support system for the chaotic management of transport infrastructure with the synthesis of self-organization and self-development processes, taking into account the restrictions imposed. The P-Integration synergetic pattern is an architectural pattern for synthesizing a decision support system that describes plug-in interaction strata. The generalized pattern is the basis of the design and the system as a whole, and individual plug-ins that implement a narrow range of specialized tasks of the domain. The P-Integration synergetic pattern describes the limitations and interfaces of plug-ins that make up the decision support system, ensuring their integration and joint operation. The integrating environment contains a platform for executing transaction scenarios, basic functionality for application interaction, logging services and monitoring of the state of the integrating environment.

The declarative, methodical and implementing strata form the integrating environment of the P-Integration synergetic pattern, which contains the process of transferring data from the declarative stratum, using methods from the methodical stratum, assigning data and methods to the implementing stratum.

Different patterns represent the internal affiliation of the system, largely reflecting the peculiarities of its specific implementation in solving problems of transport infrastructure management, and all other components are instances of various architectural components.

The methodical stratum contains the patterns of the supervisor of the decision support system, the patterns of the masters of database design, the models of objects and processes of the domain, the patterns of the masters of the design of plug-ins. The Pattern Database Wizard generates an object model base template in accordance with the model it is specified.

In the generated class pattern of the model, proper storage structures are created only in relation to those classes whose objects will actually constitute object models of the domain. Objects of classes describing abstract, generalizing concepts may not be included in object models. However, the properties and methods described in these classes are represented in an object-oriented database. This occurs in cases where at least one class derived from “abstract” classes has a status indicating the presence of objects of this subclass in the object model. Model Wizard automates the development of model supervisors. A model supervisor is an architectural component of a system through which all components of an architecture form links. This unification allows us to state a high degree of openness in the architecture of the decision support system in managing the transport infrastructure, its ability, as a tool, to evolve.

3 P-MODEL IMPLEMENTATION

We consider the implementation of the P-model of the ITSGIS intelligent transport geo-information system: the “Strategy_ITSGIS” pattern (Mikheev et al., 2012).

Task. It is necessary to design changeable, but reliable algorithms or strategies of behaviour.

Decision. A pattern encapsulates an object’s algorithm, simplifying its specification and making it independent of other algorithms and clients that use it. Encapsulation strategy in a separate class allows you to change the behaviour of the object dynamically. “Strategy_ITSGIS” allows you to configure a class by specifying one of the possible behaviours. The mechanism of inheritance makes it possible to isolate the functionality common to all algorithms, thereby supporting a variety of algorithms or behaviours. Obviously, to add a new strategy, you need to create an independent class and implement the necessary functions. Similarly, only one class will be affected to change or delete a strategy. When describing the behaviour of an object by several methods, the “Strategy_ITSGIS” pattern reduces the number of conditional statements in the program code. The conditional operator will need no more than once to select a specific strategy. You can use the “Strategy_ITSGIS” pattern, for example, when choosing an encryption algorithm.

Example A. A system for automatically constructing a transport network model on a thematic layer of an electronic map. When constructing a model of a transport network consisting of several “universal” sections, algorithms of the same meaning are used, but used for different conditions of dislocation of these sections on the map in ITSGIS. These are algorithms for constructing intersections,

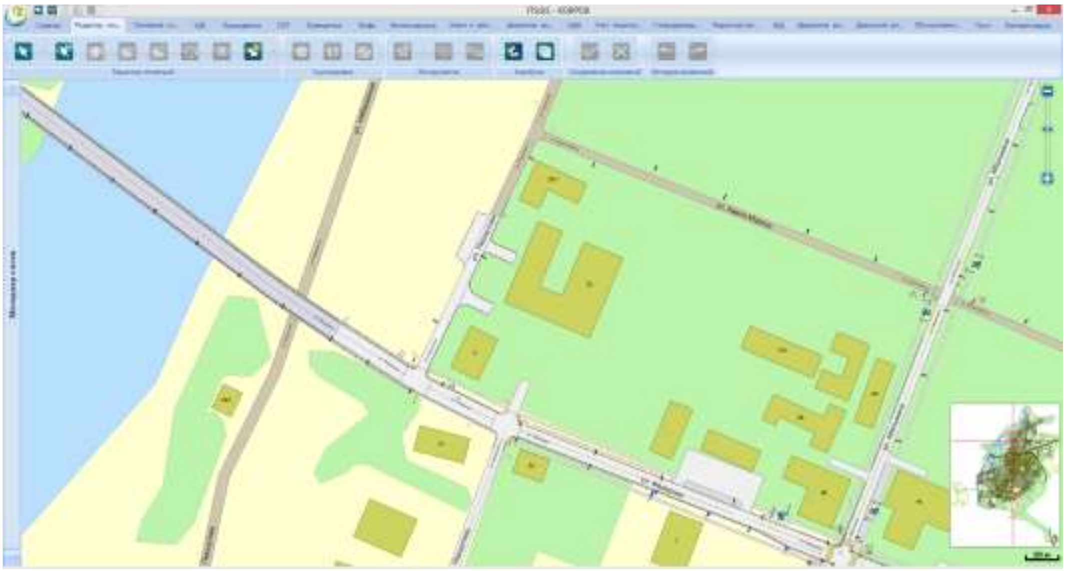

Figure 2: Synthesis of universal transport network structures in ITSGIS.

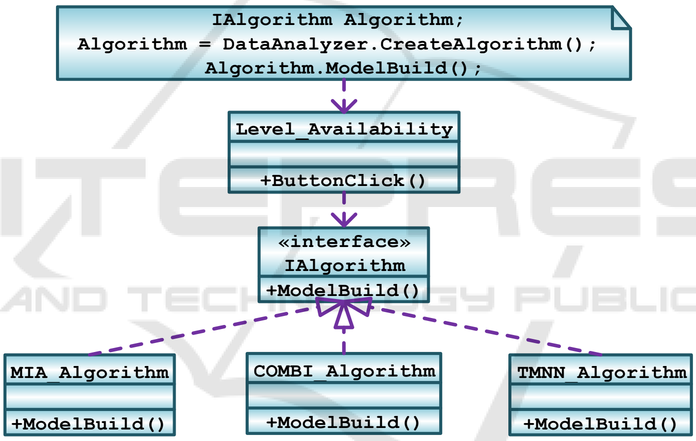

Figure 3: “Strategy_ITSGIS” pattern.

pedestrian crossings, railway crossings, tunnels, overpasses, bridges, hauls of various configurations (dead ends, turns, broadenings, etc.). The site construction object applies the appropriate algorithm depending on the conditions of its construction and visualization on the map (Figure 2).

Example B. The plug-in of the intellectual analysis of the state of spatially coordinated objects. The design of ITSGIS takes into account the extensibility of the system in terms of adding new data research algorithms, the use of which should not differ from the use of existing ones in ITSGIS. The plug-in of the intellectual analysis of the state of geo-objects allows to determine the dependence of the level of accidents on a part of the transport network on various factors that are constantly present or occur during the functioning of the transport infrastructure: the presence of children’s educational institutions, pedestrian crossings, road signs, emergency recovery works, traffic accidents and other. Figure 3 shows the class diagram for applying the “Strategy_ITSGIS” pattern. The “Level_Availability” client class has access to the interface assembly and therefore can define a variable of type “IAlgorithm”. The client class receives a link to one of the algorithms located on the server through the creator class. The decision about which class of algorithm to create is made by the user, calling one of the overloaded methods of the creator class. Adding a new class of algorithm to the existing ones will not break the overall system architecture. The “Strategy_ITSGIS” pattern provides the extensibility of the ITSGIS system by adding new algorithms for constructing a regression model. Each algorithm is described in a separate class

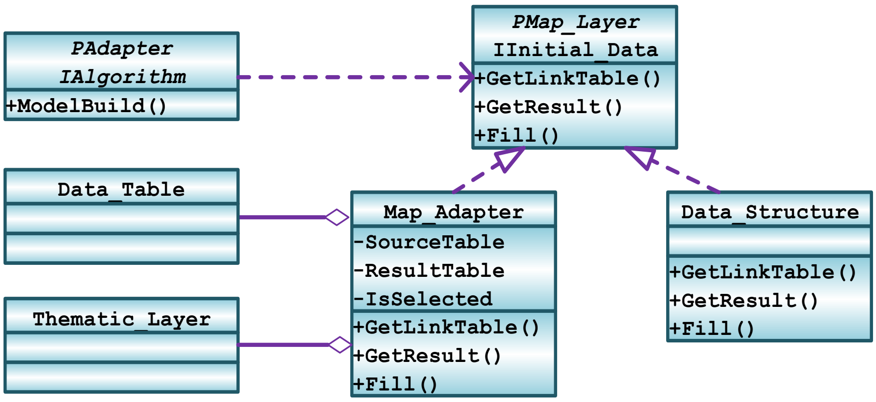

Figure 4: "PMap_Layer_Adapter" pattern.

("TMNN_Algorithm", "MIA_Algorithm", "COMBI_Algorithm") implemented by the "IAlgorithm" interface. In the "Level_Availability" client class, a variable of "IAlgorithm" type is defined, which is initialized by an instance of one of the classes of the algorithm chosen by the user.

Task. It is necessary to design a decision support system for the chaotic management of the transport infrastructure with the synthesis of self-organization and self-development processes, taking into account the restrictions imposed.

Decision. The "PMap_Layer_Adapter" pattern of synthesis of the thematic layer of the electronic map of the geographic information component of the intelligent transport infrastructure management system is based on the "PAdapter" pattern for converting information from a map display of objects into a form for the functioning of neural network artificial intelligence methods. Geographical visualization of information is presented on an electronic map in the form of thematic layers, each of which displays a specific type of geospatial attribute-oriented models of geo-objects.

Example A. Plug-in analysis of correlated spatial-coordinated geodata based on the processes of self-organization and self-development of various types of spatial geo-objects. Methods for analysing correlated spatially coordinated geo-data are developed on the basis of implementation patterns.

The "PMap_Layer_Adapter" pattern converts the interface of one class to the interface of another, aggregates the spatially coordinated data rendered on the corresponding thematic layers and stored in the corresponding system database tables, and operates with artificial intelligence methods that return data in general form data structures.

The class diagram of "PMap_Layer_Adapter" pattern for the system of intellectual analysis of spatial-coordinated geo-objects is presented in Figure 4. "IAlgorithm" is an interface that is inherited by the algorithms for studying the attributes of transport infrastructure objects. "Map_Adapter" is an adapter that brings the interface of spatially coordinated objects stored in instances of "Data_Table" and "Thematic_Layer" to the "IAlgorithm" interface.

4 CONCLUSIONS

The stratified pattern model is used as an informational, methodological, and implementation basis for designing a decision support system of transport infrastructure management.

The synthesis of a decision support system of transport infrastructure management is based on a fundamental methodological basis, defined by an object-oriented paradigm that establishes the primacy and atomicity of object categories, taxonomic and aggregate patterns of properties and relations between objects.

REFERENCES

Cai, S., Gallina, B., Nyström, D., Seceleanu, C., Larsson, A., 2018. Tool-supported design of data aggregation processes in cloud monitoring systems. In *Journal of Ambient Intelligence and Humanized Computing*.

Coad, P., Yourdon, E., 1991. *Object-oriented analysis*, Englewood Cliffs, NJ: Yourdon press.

Golovnin, O. K., Mikheeva, T. I., 2018. Attribute-driven network-centric urban transport process control system modeling. In *Journal of Physics: Conference Series*.

Grenander, U., 1993. *General Pattern Theory*, Oxford University Press.

Kabir, S., Yazdi, M., Aizpurua, J. I., Papadopoulos, Y., 2018. Uncertainty-aware dynamic reliability analysis framework for complex systems. In *IEEE Access*.

Kleppmann, M., 2017. *Designing data-intensive applications: The big ideas behind reliable, scalable, and maintainable systems,* O'Reilly Media.

Limayem, M., Khalifa, M., Chin, W. W., 2004. CASE tools usage and impact on system development performance. In *Journal of Organizational Computing and Electronic Commerce*.

Maksimov, M., Fung, N. L., Kokaly, S., Chechik, M., 2018. Two decades of assurance case tools: a survey. In *International Conference on Computer Safety, Reliability, and Security*. Springer.

Mikheev, S. V., Mikheeva, T. I., Malykova, K. A., Mikhaylov, D. A., 2012. Disposition of objects of a transport infrastructure in the GIS ITSGIS. In *CSIT'2012, 14th International Workshop on Computer Science and Information Technologies.*

Petzold, R.G., Freund, D.M., 1990. Potential for geographic information systems in transportation planning and highway infrastructure management. In *Transportation Research Record*.

Šelih, J., Kne, A., Srdić, A., Žura, M., 2008. Multiple-criteria decision support system in highway infrastructure management. In *Transport*.

Speranza, M. G., 2018. Trends in transportation and logistics. In *European Journal of Operational Research*.

Tomingas, K., Kliimask, M., Tammet, T., 2015. Data integration patterns for data warehouse automation. In *New Trends in Database and Information Systems*. Springer.

Vanier, D. J., 2004. Geographic information systems (GIS) as an integrated decision support tool for municipal infrastructure asset management. In *Proceedings of the CIB 2004 Triennial Congress*.

Wood, T., Ramakrishnan, K. K., Hwang, J., Liu, G., Zhang, W., 2015. Toward a software-based network: integrating software defined networking and network function virtualization. In *IEEE Network*.