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Research paper

Information and decision modelling in civil engineering

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Abstract: Information and decision projects in the area of civil engineering are usually complex and heterogeneous. This, in turn, requires the use of IT solutions to support them. The selection of the appropriate models for data or knowledge representation, which are the information resources of such systems in connection with the selection of analytical and decision models, can be considered as one of the elements of the rationalization of engineering projects. The approach that takes account of the significant complexity and heterogeneity of problems is a system approach with the use of an object-oriented way of organizing data or knowledge. Not only does it ensure efficient modelling of information and decision processes in the field of engineering projects (also in crisis situations), due to the uniformity of the model approach, it also allows for maintaining the continuity of the implementation of complex processes of various specificity, e.g. the different levels of structuring or the randomness of partial problems.

Keywords: transport infrastructure engineering – bridges, data or knowledge representation models, IT support for engineering projects

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1. Introduction

Engineering projects at the individual stages of construction or reconstruction of damaged transport infrastructure facilities can be classified as complex ones, both from a technical and organizational point of view. Moreover, an additional difficulty is often posed by the time constraints imposed on the implementation of analytical and decision-making processes. Such a situation necessitates continuous improvement in terms of planning, designing and organizing the construction (reconstruction) of engineering facilities.

In engineering practice, the solution of a problem situation usually requires taking multistage and heterogeneous actions. In addition, the sets necessary to analyze feasible decisions are usually large, which, with the need to additionally take account of the randomness of phenomena and the incompleteness of information resources, imposes on the decision-maker - engineer the need for a special approach to the problem being solved. It seems that an important aspect of this approach is to see in each individual operation (calculation, decision) the entirety of the decision problem it concerns. A holistic approach to decision-making tasks, as opposed to a reductionist one, makes it possible to analyze and consider the influence of individual elements of the whole on other elements and, which is of equal significance, the impact of each of these elements on the functioning of the whole.

This article focuses mainly on the specificity of models and modelling processes in the area of civil engineering. It is currently of particular significance when a transport infrastructure program is a government program. This means the modernization of roads, and thus the redevelopment of bridges by widening roads or building new bridge crossings. However, during the redevelopment or reconstruction of permanent road structures, it is necessary to provide by-pass or temporary bridges, which can be constructed from the elements of temporary foldable bridges. That is why, the described information and decision-making undertakings in civil engineering are illustrated mainly with examples related to the technical design of bridge structures and the technology and organization of their construction in special conditions (e.g. redevelopment of bridges or their reconstruction after a flood wave).

2. Role of systemic approach in information and decision tasks in civil engineering

The solution of a problem situation for engineering projects is reached as a result of the analysis of various factors, such as the needs related to the use of the facility, the resources of local materials or the size of the potentials of various categories (human, equipment) that can be employed in the construction/reconstruction of the facility. Not only should the impact of each factor on the area of feasible solutions be taken into account, but also the interrelationships between individual factors, while the entire analysis should be conducted taking account of the impact of the geographical environment on the needs, resources and conditions of engineering activities.

The necessity to include in the analysis information resources with a very complex structure (each of the system objects is characterized by a large number of attributes – and these have different values) and the network of interrelationships between the elements of the system is a huge inconvenience.

Among the various approaches to solving engineering problems in construction, given the above observations, what certainly deserves attention is the holistic approach. It assumes regarding the object of interest as a whole separated from the reality under examination, assigning the name of a system to this whole [1, 10]. This whole under consideration can be a bridge, being part of a larger whole (road infrastructure of the region) and consisting of smaller units connected with each other (spans, supports, etc.).

The systemic approach seems to be justified in the case of engineering activities (particularly decision-making processes) as regardless of whether the subject of these activities is a complex engineering object (road, bridge) or the organization of any engineering project (e.g. a temporary water crossing), decision-making processes always encompass numerous aspects of the problem and it is always necessary to take account of the influence of the environment (super-system) on the system being studied. An example of a systemic approach to bridge construction is presented in Table 1.

Table 1. Bridge construction from a systemic perspective

System	Object	Attribute
Bridge construction	Crossing, bridge	Location, type of span structure and supports
	Construction equipment	Yield, type, quantity
	Materials	Kind, type, supply
	Contractors	Qualifications, number
	Costs	Method of settlement

Each system (including an engineering one) can also be regarded as a multi-channel information converter, which means that the entire information infrastructure can be identified in it. Information about the boundary of the system, its elements, relations between them and the relations between the system and the environment can be viewed as a subsystem of the system under consideration.

The information image of the system can be created as a result of various methods of transforming the area of the reality into the area of the abstract. From the point of view of engineering activities, particular significance can be attributed to system modelling and heuristic activities [11].

System modelling is characterized by a significant level of the formalization of the language used to describe reality. Most often it is the language of mathematics, combined with an algorithmic approach to solving problems. However, a significant part of engineering activities exceeds algorithmic (structural) solutions. A whole range of engineering decision-making problems, including the classification of objects based on their condition or the diagnosis and prediction of the condition of engineering systems, may require a heuristic approach, based on the experience and knowledge of the decision maker, and not on the construction of formal algorithmic models, which one does not have for these problems [12].

3. Information modelling in civil engineering

The applied formalisms of information resources representation should meet the requirements of the systemic approach while maintaining the full scope of information generated by the data source (the system under consideration).

With the principles of the systemic approach as a starting point, presented in p. 2 (constatation – everything depends on everything) in an object-oriented approach, it can be assumed that every *t* – phenomenon can be presented by relations as in Fig. 1.

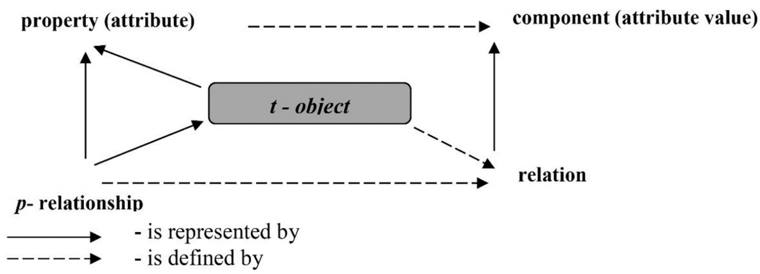


Fig. 1. Relation schema of relationships of object [7]

The relationships between the descriptive model of the object and the relational model can be expressed as follows:

– every object (set of objects) and every family of relationships between these objects is represented by a relation, i.e. every *t – object* and every *p – relationship* should be described by a relation schema;
– each family of properties (attributes) of objects or relationships is represented by a relation component.

Thus, it is assumed that:

– relation means *t – object* or *p – relationship*;
– its component denotes the name of the corresponding *t – property*.

Such a form of notation makes it possible to define:

– bridges as well as their components as objects (sets of objects);
– object attributes and their values;
– states of objects and relations between them;
– inference rules, and
– control conditions.

An object expresses a certain real category or a certain concept. Thus, it can be considered that an object is an instance of a concept. Every concept, in turn, is an individual element of a separate area of reality, with its intension (content) and extension (scope).

A set of objects is a collection of these objects to which a given concept applies. Fig. 2 presents the concept triple of object – intension – extension for a temporary bridge, which graphically illustrates the way of thinking about these three aspects.

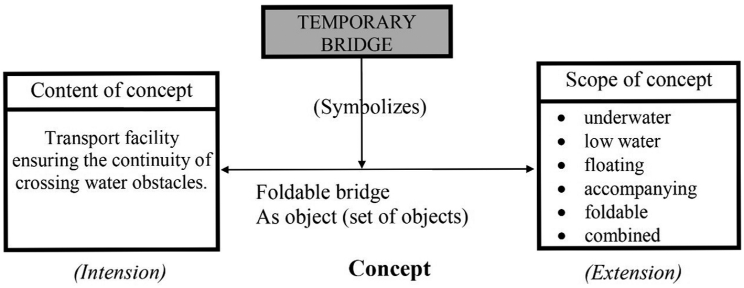


Fig. 2. Concept triple for a temporary bridge [5]

The DMS-65 folding road bridge was adopted for further considerations in the information and decision-making modeling, the possible design layouts of which are shown in Fig. 3.

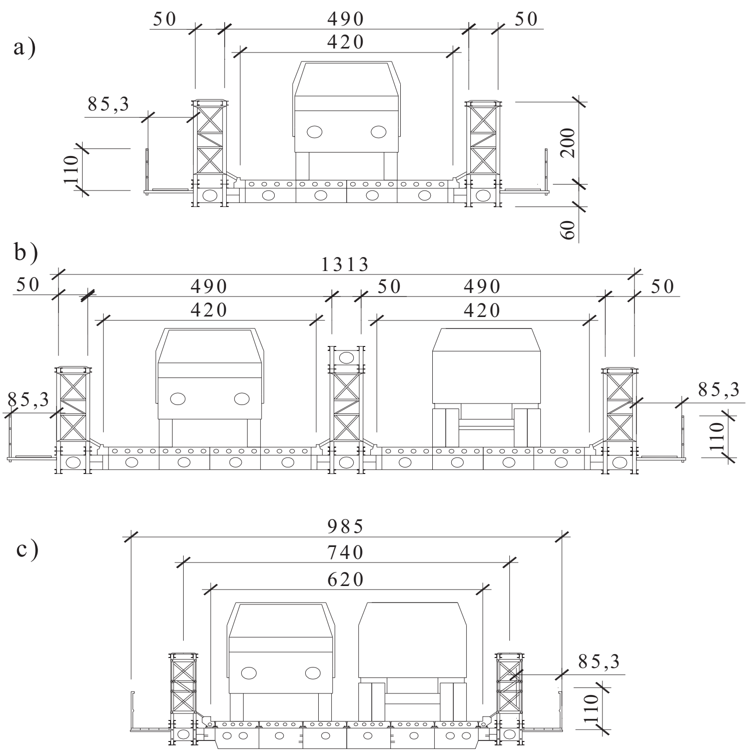


Fig. 3. DMS-65 constructions: a) one-carriageway, b) two-carriageway layout, and c) modernized structure [9]

For depicting the connections between objects, appropriate mechanisms can be used in the form of:

– relations, which make it possible to treat relationships as a whole;

– mappings, which assign objects of one type to objects of another type.

By adopting a specific (dedicated) bridge construction agent, e.g. a foldable road bridges company (ksmd), with the object-oriented approach it is possible to write down certain dependencies between working teams (subunits – ksmd platoons).

The object-oriented approach allows one to treat events as objects. This means that one can operate on events and link them with relations. While events are changes of the state of the object, it is the operations that make these changes, which does not mean that every operation must end with an event. For instance, the fact that a support was being built does not have to indicate that it will eventually be made.

The method of the DMS-65 foldable bridge construction with the object-oriented approach was adopted as a specification of the way of performing operations. Fig. 4 shows two ways of method representation: in coded form and as a diagram.

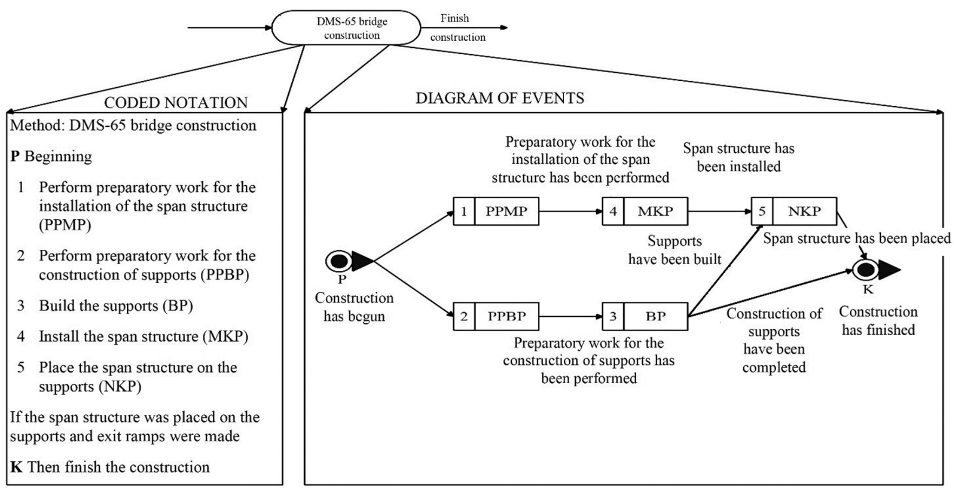


Fig. 4. Ways of method representation in coded form and as a diagram [7]

The first method has a linear nature and is quite often used by programmers. The other one can be used both with sequential and concurrent specification techniques.

When analyzing the diagram presented in Fig. 4, it can be noted that for one event to occur, other events related to other objects may or must happen. This means that changing the state of one object may or must require a change of the state of many other objects. For instance, the occurrence of object 5 requires the completion of other objects 3 and 4.

The object-oriented approach, besides the relational one, is the most often used method of representing the information complexity of systems in the analysis stage (modelling) of IT systems [12].

4. Modelling of analytical problems in civil engineering

Analytical projects in civil engineering are characterized not only by their significant complexity, but also substantial heterogeneity. For instance, in the case of the construction of a road foldable bridge, such analyses may include the following:
– analysis of bridge structure solutions;
– analysis of technological and organizational solutions of bridge construction;
– analysis of water obstacles;
– analysis of the technological and organizational process.

Completion of analytical tasks, due to their multifacetedness, often requires access to a variety of information sources (catalog, aggregated at different levels of generality or historical data – time-variant dependent). For instance, undertakings, lists and analyses of possible solutions made during a preliminary bridge structure design, including, apart from computational analyses, an analysis of structural solutions, consideration of states of emergency – possible failure scenarios, as well as economic and organizational analysis of the undertaking, require complex, diverse information feeds. In addition, when analyzing the operating conditions of the designed structure, it seems reasonable to use the description of environmental conditions, evaluation of the type of land, as well as various types of data aggregates (concerning the intensity of traffic or loads of goods transported in certain time intervals). It turns out that in such cases the "multidimensionality" of analyses makes one look for other models of data organization, e.g. cubes, snowflakes, stars or constellations of facts [6], which are more effective than "two-dimensional" structures.

Figure 5 shows a sample cube structure for bridge structure construction.

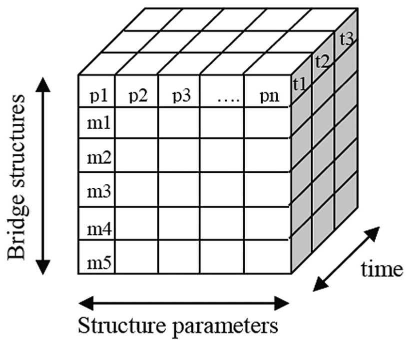


Fig. 5. Use of a multidimensional structure to store information about bridge structures [8]

Multidimensionality of data organization is obtained by complementing a rudimentary, two-dimensional structure, referred to as fact table, with further dimensions (table structures), referred to as criteria dimensions (e.g. time, region – location). In the example shown in Fig. 4, the fact table is made up of the following dimensions: bridge structures and structure parameters. A single row of this table includes information about selected attributes (parameters) of one bridge structure that is unique in the entire table. A collection of rows of this table encompasses a complete set of information on all structures of this type. An additional dimension (time) provides access to the history of bridge states in the parameters ($p_1, \ldots, p_n$) at certain times (or intervals).

In solving real analytical problems in road structures construction, a fact table will not be identified only with a set of parameters (attributes) of bridge structures. The same unnormalized table may also contain information on bridge structure components: spans, supports, etc.

5. Decision-making problems modelling in civil engineering

Regardless of the type of engineering problem, the selection of methods, techniques and tools for its rational solution should always be preceded by its identification and analysis. Such an analysis, in addition to the general specification of the problem, makes it possible to:

– identify information sources;
– define the problem in detail;
– determine the possibilities of supporting the solution of the problem.

The criteria on the basis of which the best solution is selected should be established already at the analysis stage, because they change only slightly in the course of further considerations. Depending on the type of problem, reliability, safety, ease of use, etc. are present in virtually all cases. What may, however, change substantially is their relative importance. The dominant criterion has a definite influence on the preference for certain variants of the solution. The essence of identifying the area of solutions is presented in Fig. 6.

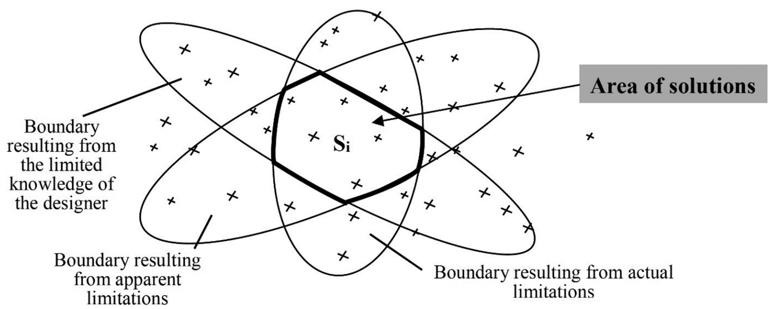


Fig. 6. Area of solutions to an engineering problem [3]

Using Fig. 6, one can compile information that should be taken into account in a detailed problem analysis. For instance, with regard to a foldable bridge, the following may be included:

– limitations of the knowledge base related to the data from the reconnaissance of the bridge construction area or the contractor's capabilities at a given time;

– actual limitations – resulting from the inability to let through the required loads with a particular span length;
– apparent limitations – which may occur during the temporary reconstruction of bridges damaged after floods.

Based on the available information resources, it is necessary to find such a construction of the values of the variables of the solution S1, S2, . . . , Sn that makes it possible to maximize the C value and meets all the assumptions and limitations. The variable of the solution is an independent variable. With no limitations, the designer can freely select its various values and examine how it affects the criterion. The task of the designer (decision maker) is to select the variables of the solution so that C is rational and at the same time complies with all the requirements and limitations.

With regard to bridge construction, the following may be included:
– a limitation (a requirement for a solution) which determines e.g. the minimum bridge width or the bridge construction time;
– a solution variable (independent variable) – it concerns, for instance, structure parameters;
– a criterion (dependent variable) – it limits the allowable values of a particular criterion, e.g. bridge capacity.

Depending on the type of problem (algorithmic, heuristic), the following can be distinguished as methods of solution selection: operational research methods, constant properties contrasting (ANKOT), and probabilistic methods.

Despite some special features of particular problems, in nearly all cases the process of taking a rational decision should comprise the following stages:
1) selection of evaluation criteria and prioritization of their importance;
2) specification of the expected properties of individual solutions in view of the above criteria;
3) comparison of solutions on the basis of expected properties;
4) selection of the final, possibly simplest solution.

For numerous types of decision-making problems, the very procedure (algorithm) of their solution can be considered recognized and formalized (e.g. the Simplex algorithm, or forecasting for the phenomena with linear trend estimation based on time series analysis).

However, there are a significant number of problems in the area of construction whose structure is not well-known. One such example includes the problem of forecasting the technical condition of a bridge. The functions describing the wear of individual bridge elements at given time moments are usually non-linear, and their forms, dependent on numerous factors (e.g. operating conditions), are difficult to identify.

Problems with a poorly recognized structure also include any problems for which model parameters are qualitative. The difficulty in expressing these parameters with numerical values makes the task impossible to solve with analytical methods.

A large, potential number of decision-making problems with the above-mentioned properties means that problems with a poorly recognized structure should be treated as an important category of tasks in the field of engineering projects management, mainly due to the limited possibilities in terms of methods, techniques and technologies (including

IT ones) supporting their solution. Such methods may include simulation or heuristic methods [13].

Among the various possible solutions that can be employed in the above-mentioned cases, the methods that include the preparation (acquisition and formalization) and use of expert knowledge can be considered quite well recognized and successfully verified in practice [2]. Knowledge acquisition and processing is the responsibility of knowledge engineers. They are responsible for extracting knowledge both from the expert and from other sources. The acquired knowledge, despite its differences in nature, should then be formalized with uniform notation systems.

For the formal representation of facts, the triples of ⟨OBJECT⟩, ⟨ATTRIBUTE⟩, ⟨VALUE⟩ are most often used [4]. Mapping is based on a static approach to the dependencies between the extracted objects and the properties of these objects. In the case of rule formalization, the following can be used: frameworks (procedural and declarative representation), semantic networks (declarative representation), and decision rules.

Rules express not only dependencies between processes, but also contain the dynamics of causes and effects, i.e. they determine when operations are triggered.

For instance, with regard to the DMS-65 bridge construction, the rule can be expressed as follows:

If you are building an SPS-69 intermediate support on water,

Then perform the following operations:

– assemble a pile driver ferry;
– assemble a pile driver on the ferry;
– position the pile driver ferry in the axis of the support;
– build a pile grate;
– assemble a frame superstructure.

It follows from the rule that certain control conditions must be met for the process to be completed. With regard to the previously mentioned example, the control conditions can be written as in Fig. 7.

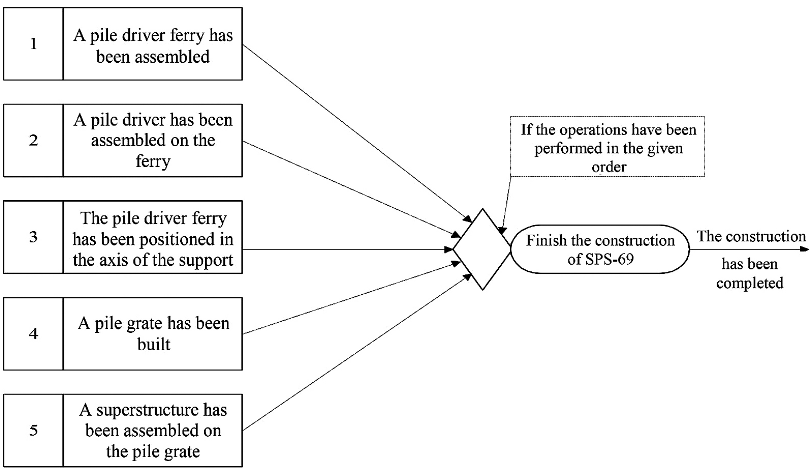
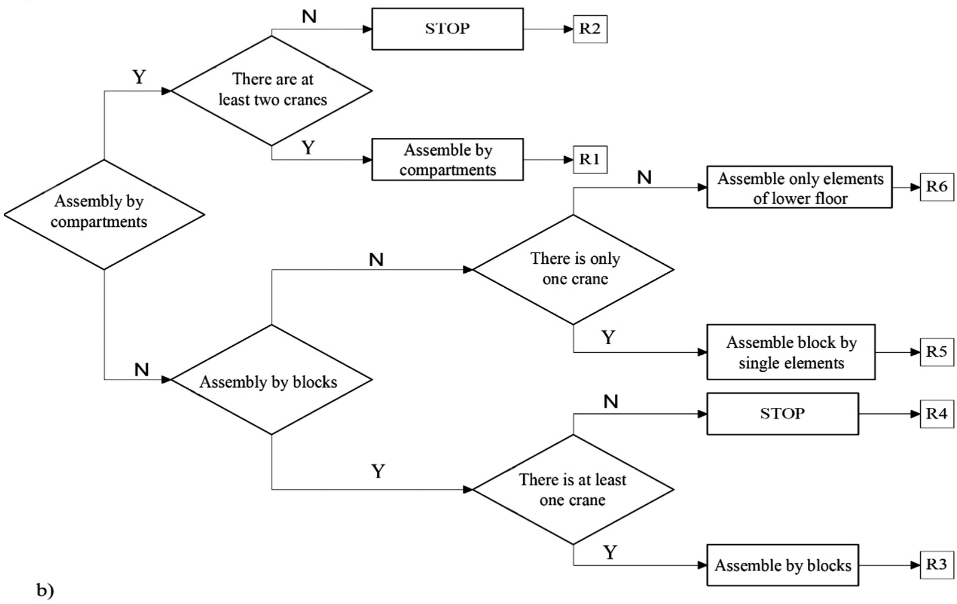


Fig. 7. Method of expressing multiple control conditions [8]

The notation of control conditions may vary. Usually, conditions are given in a disjunctive form, which is expressed in a typical rule entry of “if . . . then”. Fig. 8 shows a rule-based notation for the assembly of the span structure of the DMS-65 bridge with compartments in the form of a diagram and a decision table. The use of decision rules to represent knowledge in the area of bridge construction seems particularly justified. It is supported not only by the high transparency of elementary portions of knowledge recorded with this technique, but also by the ease of their modification and the fact that it is a form commonly accepted by most skeleton expert systems [4].

a)



b)

		Sections		Positions of rules					
				R1	R2	R3	R4	R5	R6
IF:	CONDITIONS	Assembly by compartments?		Y	Y	N	N	N	N
		Are there at least two cranes?		Y	N	-	-	-	-
		Assembly by blocks?		-	-	Y	Y	N	N
		Assembly by single elements?		-	-	-	-	Y	Y
		Is there at least one crane?		-	-	Y	N	-	-
THEN:		Is there only one crane?		-	-	-	-	Y	N
	ACTIVITIES	STOP – no assembly		-	X	-	X	-	-
		Assemble	by compartments	X	-	-	-	-	-
			by blocks	-	-	X	-	-	-
			by single elements	-	-	-	-	X	-
			only elements of lower floor	-	-	-	-	-	X

Fig. 8. Rule-based notation for the assembly of the DMS-65 span structure with compartments in the form: a) a diagram, b) a decision table [8]

Rules make it possible to define not only cause and effect relationships between events or operations that occur in the bridge construction process, but also to control the dynamics of causes and effects, i.e. they determine when operations are triggered.

The formally recorded knowledge should then be implemented in the selected expert system. The implementation stage encompasses all the information resources that make up the knowledge base, i.e. the decision rule base, the fact base and possibly databases – including external ones. The set of final conclusions has to be specified by the expert and the task of the system is only to select the appropriate element from this set. Among the various solutions in the area of knowledge representation in expert systems (rules, semantic networks, frames) rule-based systems deserve special attention due to the simplicity of knowledge notation and the transparency of the structure.

6. Conclusions

When analyzing information and decision-making undertakings in civil engineering, it can be concluded that in this case one deals with the processes that are often unique and heterogeneous both in terms of the category of analytical or decision-making problems and the types of information resources used in their implementation. The need to perceive partial processes in the context of the entire undertaking, with the simultaneous need for IT support for these undertakings, makes one look for a homogeneous approach to individual problems as well as a coherent method of the organization and formalization of information resources. Only by taking account of such conditions is it possible to implement heterogeneous undertakings with a different level of structure or randomness.

Among the available categories of approaches that enable both the modelling of a problem situation and the organization of information resources with regard to engineering projects, the holistic approach can be recommended, with particular emphasis on object-oriented notation. The great importance of such an approach within information and decision modelling should be attributed to the possibility of building and using homogeneous object notations in the modelling of complex information problems and various decision-making problems, including problems considered to be poorly structured, which are so characteristic of crisis situations. More importantly, using the ⟨OBJECT⟩, ⟨ATTRIBUTE⟩, ⟨VALUE⟩ notation, one can also precisely model information resources of considerable complexity, necessary for the completion of multidimensional engineering analyses. The diversity of engineering problems and the related diversity of categories of information feeds, necessary to solve them, do not have to necessitate the use of different, inconsistent notations with regard to the organization and formalization of these resources. This seems to be particularly important in the context of the need to maintain the continuity of complex information and decision-making processes, particularly in the conditions of their IT support.

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Modelowanie informacyjno-decyzyjne w obszarze inżynierii lądowej

Słowa kluczowe: budownictwo komunikacyjne – mosty, modele reprezentacji danych lub wiedzy, wspomaganie informatyczne przedsięwzięć inżynieryjnych

Streszczenie:

Przedsięwzięcia inżynieryjne w poszczególnych etapach budowy, czy odbudowy zniszczonych obiektów infrastruktury transportowej, można zaliczyć do skomplikowanych, zarówno z punktu widzenia technicznego, jak i organizacyjnego. Ponadto dodatkowym utrudnieniem są często ograniczenia czasowe nałożone na realizację procesów analityczno-decyzyjnych. Taka sytuacja wymusza konieczność ciągłych udoskonaleń w zakresie planowania, projektowania oraz organizacji budowy (odbudowy) obiektów inżynieryjnych.

W praktyce inżynierskiej rozwiązanie sytuacji problemowej wymaga najczęściej podjęcia wieloetapowych i niejednorodnych działań. Dodatkowo, zbiory koniecznych do przeanalizowania decyzji dopuszczalnych są zazwyczaj liczne, co przy konieczności dodatkowego uwzględniania losowości zjawisk i niekompletności zasobów informacyjnych nakłada na decydenta – inżyniera konieczność specyficznego podejścia do rozwiązywanego problemu. Wydaje się, że istotnym aspektem takiego podejścia jest dostrzeganie w każdym działaniu cząstkowym (obliczeniach, decyzji) całości problemu decyzyjnego, którego to działanie dotyczy. Holistyczne podejście do zadań decyzyjnych, w odróżnieniu od podejścia redukcjonistycznego, daje możliwość analizy i uwzględniania wpływu poszczególnych elementów całości na inne elementy i, co równie ważne – wpływu każdego z tych elementów na funkcjonowanie całości. Za główny cel artykułu przyjęto zaprezentowanie holistycznego podejścia w procesie informacyjno – decyzyjnym związanym z budową mostów w sytuacjach kryzysowych, bazując na wojskowych konstrukcjach składanych.

W niniejszym opracowaniu uwagę skupiono głównie na specyfice modeli oraz procesów modelowania w obszarze budownictwa lądowego. Ma ono obecnie szczególne znaczenie, kiedy program infrastruktury komunikacyjnej jest programem rządowym. Oznacza to modernizację dróg, a tym samym przebudowę mostów poprzez poszerzenie jezdni, czy budowę nowych przepraw mostowych. Jednak na czas przebudowy lub odbudowy stałych obiektów drogowych należy zapewnić mosty objazdowe bądź tymczasowe, które mogą być montowane z konstrukcji tymczasowych mostów składanych. Dlatego też opisywane przedsięwzięcia informacyjno-decyzyjne w budownictwie lądowym zobrazowano głównie przykładami, odnoszącymi się do projektowania technicznego obiektów mostowych oraz technologii i organizacji ich budowy w warunkach szczególnych (np. przebudowa mostów lub ich odbudowa po przejściu fali powodziowej).

Wśród różnorodnych sposobów podejścia do rozwiązywania problemów inżynierskich w budownictwie, wobec powyższych spostrzeżeń, na uwagę zasługuje z pewnością podejście holistyczne – całościowe. Zakłada ono traktowanie obiektu zainteresowań, jako całości. Rozpatrywaną całością może być most, będący częścią całości większej (infrastruktury drogowej regionu) i składający się z powiązanych ze sobą całości mniejszych (przęsła, podpory, itd.).

Podejście systemowe wydaje się o tyle uzasadnione w przypadku działań inżynieryjnych (zwłaszcza procesów decyzyjnych), że niezależnie od tego, czy przedmiotem tych działań będzie złożony obiekt inżynieryjny (droga, most) czy też organizacja jakiegokolwiek przedsięwzięcia inżynieryjnego (np. tymczasowej przeprawy wodnej), procesy decyzyjne zawsze obejmują wiele aspektów problemu i zawsze należy uwzględniać wpływ otoczenia (nadsystemu) na system będący przedmiotem badań.

Przedsięwzięcia o charakterze analitycznym w obszarze inżynierii lądowej charakteryzują się nie tylko znaczną złożonością, ale także dużą niejednorodnością. Jeśli za przykład wziąć budowę drogowego mostu składanego to, jako przykłady takich analiz można wskazać m. in.: analizę rozwiązań konstrukcji mostu; technologiczno-organizacyjnych budowy mostu; przeszkód wodnych oraz analizę procesu technologiczno-organizacyjnego.

W rozwiązywaniu rzeczywistych problemów analitycznych z zakresu budowy obiektów drogowych tabela faktów nie będzie identyfikowana jedynie ze zbiorem parametrów (atrybutów) obiektów mostowych. W tej samej, nieznormalizowanej tabeli zawarte mogą być również informacje o elementach składowych obiektów mostowych: przęsłach, podporach itd.).

Podsumowując można uznać, że podejściem umożliwiającym uwzględnienie znacznej złożoności i niejednorodności problemów jest podejście systemowe, z wykorzystaniem obiektowego sposobu organizacji danych lub wiedzy. Zapewnia ono nie tylko sprawne modelowanie procesów informacyjno-decyzyjnych w obszarze przedsięwzięć inżynieryjnych (także w sytuacjach kryzysowych), ale również, ze względu na jednolitość podejścia modelowego, pozwala zachować ciągłość realizacji złożonych procesów o różnorodnej specyfice, np. różnym poziomie ustrukturyzowania czy losowości problemów cząstkowych.

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