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Stages of Intellectualization of Engineering and Technical Support of Railway Construction

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Abstract

The article is devoted to the theoretical foundations of improving the engineering and technical support of railway construction. In the course of the study, it was determined that a number of stages of the development and implementation of technological processes contain tasks for which the use of automated design and control systems is sufficient. However, there are tasks whose solution depends on the experience and intuitive abilities of the engineer. In this case, it becomes possible to use some methods and means of artificial intelligence to solve technological, organizational and managerial tasks. In this regard, it is proposed to supplement the existing system of engineering and technical support for railway construction with a subsystem of engineering and intellectual support for the technological process of construction of a railway track object.

Keywords: technological process; railway construction; railway track object; artificial intelligence methods; railway construction management.

1. Introduction

The development of modern railway construction (RC) actualizes the problems and tasks of construction production, aimed at improving the quality of work performed. At the same time, the growth of certain requirements (technical, economic, environmental, social, etc.) contributes to the complexity of both the railway track objects (RTO) and the technological processes (TP) of their construction. In this regard, there is a need to improve the procedure for the operational development of TP and schemes in the field of construction of the roadbed, the upper structure of the track, artificial structures, the catenary, etc.

It should be noted that the stages of solving technological and organizational problems are characterized by weak structuring, blurring of the problem statement, and intuitive representation of the engineer (developer of organizational and technological documentation (OTD)) about the ways to solve it. A number of requirements and restrictions that are used in the process of developing OTD in these conditions are unclear and often do not have quantitative characteristics. In this case, the values of the construction parameters are usually set by the developer of OTD on the basis of his experience or intuition, which is explained by their implicit and often unknown interdependence (due to the large dimension and qualitative nature of TP) (Zavadskas et al., 2018a; Peldschus and Zavadskas, 2012).

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The development of TP is based on a multivariate search and a comprehensive study of alternatives. To do this, mathematical tools are actively used that take into account the multicriteria and uncertainty of knowledge in order to understand the nature of the objective function. At the same time, it is necessary to take into account the stochastic nature of RC, the vagueness and inconsistency of goals, internal and external influences. All this, in turn, significantly complicates the decision-making procedures (Zavadskas et al., 2018b).

The existing paradigm of TP development is based on solving the problems of technology, organization and planning of construction processes, taking into account the approved design (adopted design decision (DD)) of RTO, available resources in the construction (contracting) organization (CCO) and optimization measures (Fig. 1). The DD of RTO is the result of technical design and is characterized by parameters that affect the range of works (simple technological processes (STP)) that must be performed in order to obtain a completed RTO or its parts.

The technology of construction processes determines the scheme and modes of work. At the same time, technology determines resources (the list and methods of using machines, the composition of equipment and the need for workers) (Zavadskas et al., 2017).

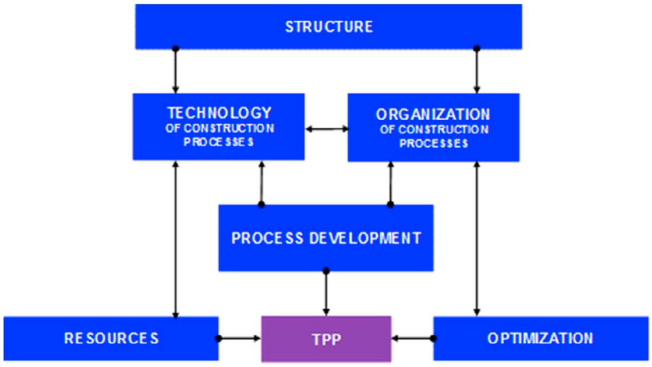

Fig. 1. An enlarged scheme of the traditional procedure for developing the technological process for the construction of a railway track object. Source – author.

The organization of construction processes establishes and characterizes the sequence, direction of development and duration of STP, as a result of which DD of RTO is realized (Zavadskas et al., 2018a). As a result, this determines the organizational structure of the technological process (OSTP), which is a set of solutions. In this case, the development of TP itself takes on a variant character. The search for the optimal TP is usually implemented in ways, in the vast majority of which the method of comparing technical and economic estimates and indicators of a number of options is used. The search for the optimal solution is carried out by varying the technological and organizational parameters, using various technical means, taking into account their technological characteristics, etc. (Zavadskas et al., 2018b).

Optimization measures relate to the field of creativity of the developer of OTD, depend on his qualifications, experience, intuition, and the depth of study of the information available in his hands. However, the low level of automation of these activities, as well as the questionable level of qualification of the developer of OTD, dictate the need to improve the procedure for developing TP from the point of view of its intellectualization (Yue, 2021). It is this approach that can help to find a rational and adequate TP for the construction of RTO in the current situation, as well as the possibility of its accounting in RC management system. This requires the definition and study of the stages and tasks of the development of TP for the construction of RTO.

Fig. 2 shows a block diagram of a variant development of TP for the construction of RTO, reflecting the existing state. However, it is not possible to automate some stages of the formation of TP. This is due to the fact that there are problems for which only calculation procedures are not enough.

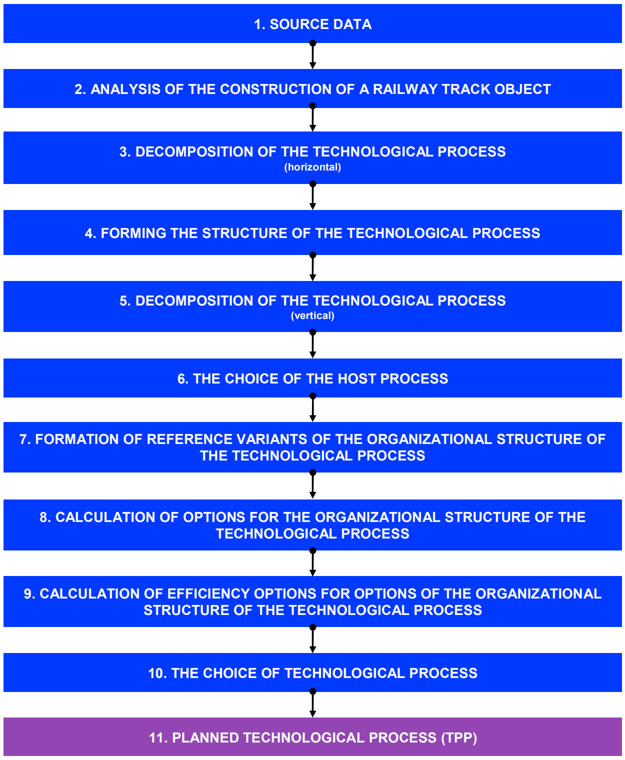

Fig. 2. Block diagram of the variant development of the technological process in the construction of railway track objects (current state). Source – author.

In this case, the active participation of a person in the development of TP is inevitable. However, with the participation of a person, the share of heuristic and subjective factors in the formation of technological solutions increases, which will undoubtedly affect the validity of the subsequent implementation of TP (Buitragoa et al., 2016). The accumulation of knowledge of the developer of OTD and decision-making in various circumstances require the use of new intellectual tools in the development and implementation of TP in RC.

In order to improve the efficiency and quality of the execution of TP, the construction of RTO, to ensure the cost-effective operation of CCO, it is necessary to take measures, starting from the preparatory stage of construction and ending with commissioning. The key element within the framework of these requirements is efficiency in both the development and implementation of TP. At the same time, modern RC is characterized by the use of new, more advanced design solutions, materials and technologies, the development of the specialization of performers and the associated large number of participants in TP. In these conditions, effective control over the organization and technology of production of works performed during the construction of RTO becomes crucial (Zavadskas et al., 2008). This can be achieved by improving the existing system of engineering and technical support (ETS) of RC through the introduction of the subsystem of engineering and intellectual support of the technological process (EISTP) of the construction of RTO.

2. Materials and methods

There is an opinion (Yue et al., 2021; Kim and Reinschmidt, 2012) that the current system of ETS cannot meet the increased and fundamentally new requirements for the management and quality of construction due to the lack of the necessary information and computing base for CCO. In addition, the system, which is based mainly on design and management methods that do not provide prompt decision-making on the totality of all the conditions for the development and features of the implementation of TP, is not able to guarantee the quality of construction that meets the new requirements.

This also applies to the construction of RTO, where the existing system of ETS primarily needs to be further improved and supplemented to meet the new requirements. First of all, the system should be aimed at ensuring the quality of work performed during the construction process and the further safe operation of RTO. This requires new approaches to creating an effective subsystem for the development and implementation of TP, properly equipped with the necessary tools.

As such a subsystem, EISTP is proposed, taking into account the specifics of the construction of RTO. This will allow you to establish the effective implementation of TP (taking into account its modeling) of the construction of RTO.

It should be emphasized that the task of engineering and intellectual support of TP includes the effective use of computers and software with elements of artificial intelligence (AI), aimed at obtaining a single final result: finished RTO of appropriate functional purpose and quality within the established time frame, planned cost and labor costs, as well as meeting modern safety requirements.

The application of the subsystem of EISTP is possible if a number of requirements and conditions necessary for the intelligent development and implementation of TP are met. The implementation of the entire set of measures is the basis for ensuring the quality of TP of the construction of RTO.

Fig. 3 shows a block diagram of the intellectual development and implementation of TP for the construction of RTO. Here, the stages are divided into three types: stages 1-3, 6, 8, 10 - within which only the calculation procedures are carried out, the stages 4, 5, 7, 11, 12 - within the framework of which it is necessary to carry out calculation and logical procedures. In this case, the selected calculation and logical procedures are a kind of links between the calculation procedures. In fact, this is the basis for creating a complex automated system with an intelligent component within the framework of the ongoing research (Leo Kumar, 2017).

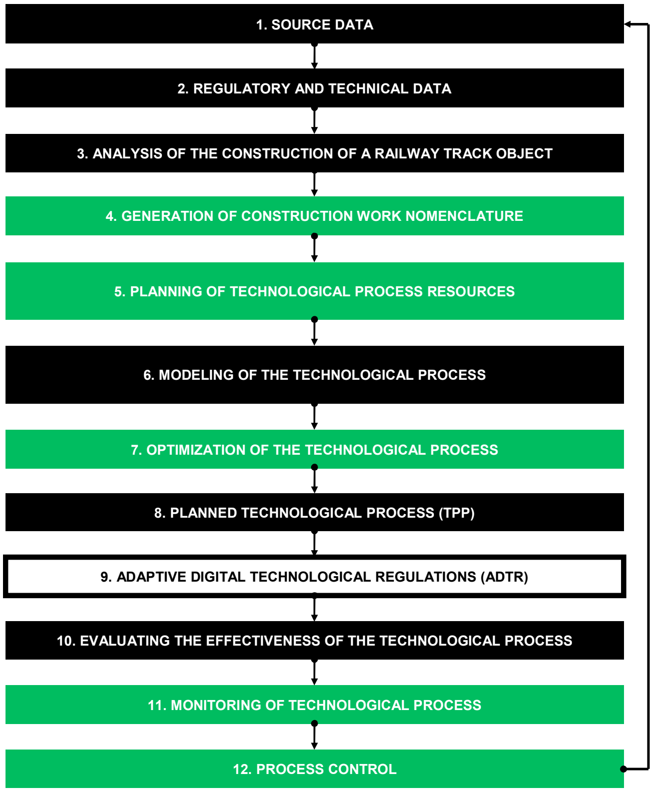

Fig. 3. Block diagram of the intellectual development and implementation of the technological process of construction of a railway track object. Source – author.

The development of systems with an intelligent component in certain cases involves the use of one or more areas of AI: expert systems (ES), artificial neural networks (ANN), genetic algorithms (GA).

AI can be defined as a scientific field whose tasks are related to the development of methods for modeling individual functions of human intelligence using software and hardware of electronic computers (Yue and Limao, 2021; Leo Kumar, 2017).

The field of solved problems that use AI technologies includes tasks that usually have the following features (Leo Kumar, 2017):

- the solution algorithm is unknown or cannot be implemented;

- if there is an algorithmic solution, but it cannot be used due to limited resources (time, memory);
- the problem cannot be formulated in numerical form;
- the goal cannot be expressed in terms of a well-defined objective function.

Taking into account the features of the tasks to be solved, the following AI tools are used to implement computational and logical procedures:

- ES of the production type for generating the nomenclature of construction works (TP operations) for the construction of RTO (Polyanskiy, 2020a; Getaneh et al., 2020; JrJung and MingNan, 2009). The software module that implements the work of ES consists of a shell in which the logical output mechanism works, and a knowledge base (KB). The logical inference mechanism is based on the processing of production rules containing a description of STP. KB provides storage of a list of STP, and production rules describing the appropriate data transformations in the field of construction of RTO (Tarek and Moncef, 2016; Kanapeckiene et al., 2010);
- GA for the evolutionary optimization of TP of the construction of RTO (Polyanskiy, 2021). The software module that implements the work of GA consists of a shell in which the formalization of the organizational structure of TP of the construction of RTO and the setting of restrictions for multi-criteria optimization is carried out (Polyanskiy, 2020b; Toklu, 2011);
- ANN for resource planning of TP of the construction of RTO (Lin et al., 2012). The software module that implements the operation of ANN consists of a shell in which resources (crews, machines and mechanisms) are assigned for the construction of RTO.As input data, information about the conditions of work, information about the available resources and capabilities of CCO is used. The operation of the module is provided taking into account the previously developed and mathematically based architecture of ANN, and its subsequent training using the algorithm of back propagation of the error on the examples of technological schemes of work (Gajzler, 2013; Gajzler and Konczak, 2015);
- ES of the probabilistic type for monitoring TP of the construction of RTO, in particular, evaluating its performance (JrJung and MingNan, 2009). The software module that implements ES consists of a shell in which the logical output mechanism works, and KB. The inference engine is based on a Bayesian knowledge processing system. KB provides storage of the list of evaluating indicators of TP, and probabilistic rules describing the appropriate transformations of data in the field of assessing the state of TP at a certain point in time;
- ANN for the regulation of TP of the construction of RTO in terms of making decisions based on the results of monitoring (Lin et al., 2012, Wang et al., 2012). The software module that implements the work of ANN consists of a shell in which it is possible to make a decision on the further implementation of TP, taking into account its assessment and forecast of development. As input data, information about the conditions of work, information about the available resources and capabilities of CCO is used. The operation of the module is provided taking into account the previously developed and mathematically justified architecture of ANN, and its subsequent training using the algorithm of back propagation of the error on situational examples (Gajzler, 2013; Gajzler, 2015).

3. Integration of the developed provisions into the existing system of design and construction management of railway track objects

The information environment currently existing in the system of ETS of RC includes data collection systems, computing infrastructure, software complexes, databases (DB). However, the return from these systems is low, and they do not give the expected effect. The reason lies in the fact that developers of OTD and builders are overwhelmed with a huge amount of poorly ordered information. It is difficult to learn and analyze it in a timely manner, and, therefore, to obtain effective technological processes. As a result, the capabilities of powerful systems are not fully utilized. Various types of OTD are materials that often serve more for "tightening the screws" in relation to CCO than for analyzing the progress of construction work and promptly responding to emerging changes.

In modern conditions, developers of OTD, as part of the implementation of EISTP, need an intelligent add-on – an intelligent automated system (IAS) that would process data from information systems and provide targeted analysis – different for different jobs in accordance with the list of possible solutions. In essence, IAS should (Wang et al., 2012):

- perform a detailed analysis of TP according to various parameters (types and volumes of work performed, production and weather-climatic conditions, time, etc.);
- identify "bottlenecks" in TP, point out the "pain points" of modern technology, poor connection of individual operations, the causes of downtime;
- use a correctly constructed principle model of TP for an objective interpretation of the information received;

- distinguish between the planned technological process (TPP) obtained at the development stage and the actual technological process (TPA) implemented during the construction of RTO;
- conduct operational analysis/forecast of the effectiveness of management decisions made;
- rely on the existing information environment that provides for the collection of information in the places of occurrence, its transfer to DB with subsequent processing and storage in ADTR (Fig. 4). The results of the analysis and recommendations for management solutions should be provided in the most convenient form (calendar schedules, flow charts, etc.).

In the future, IAS should not only analyze the work, but also make recommendations for its improvement in the form of specific control solutions. Of course, the analysis and recommendations should be targeted - in accordance with the needs and powers of a particular CCO.

Analysis is an important part of TP control procedure. A well-conducted analysis largely determines the effectiveness of management and the optimality of decisions made.

But the interpretation of the monitoring results requires an understanding of the essence of TP. That is, the developer of OTD must have some theoretical model that shows how, in principle, one can explain certain results or performance indicators. Thus, the theoretical model "tells" where to look for a possible cause (causes) certain problems in TP during its implementation. Without understanding the essence of TP, it is impossible to give a correct interpretation of the monitoring results. The analysis in this case will not prepare a rational control action.

IAS must meet the requirements of CCO and be interfaced with the application systems used.

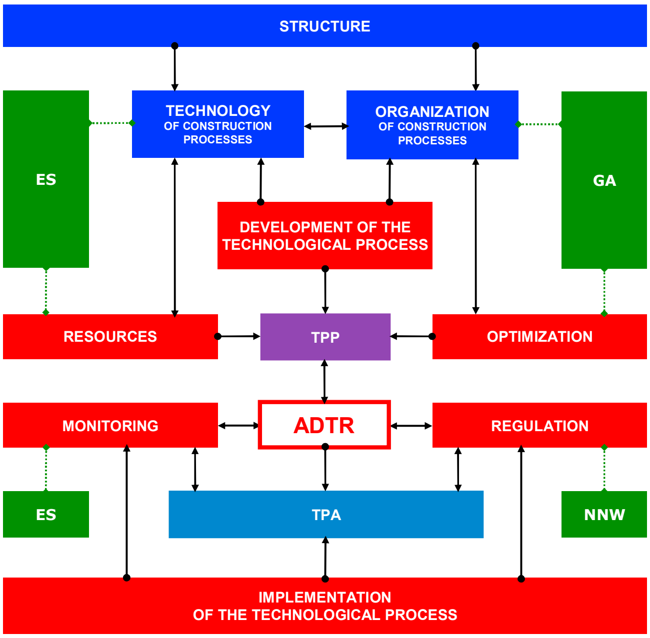

Fig. 4. An enlarged scheme of a promising procedure for automated development and implementation of the technological process of construction of a railway track object using artificial intelligence methods. Source – author.

The distributed nature of the model of EISTP determines the possibility of integrating the developed provisions into the existing system of design and management of construction of RTO on the basis of the interactions shown in Fig. 5.

These interactions show the links between the participants in the construction of RTO, the structural elements of TP, the results of organizational and technological design, and modern information software environments:

- computer-aided design systems;
- project management systems;
- means that implement information modeling of RTO (BIM);
- tools that implement 4D design.

The advantages of integrating the developed provisions, in particular IAS, into the existing system of designing and managing the construction of RTO on the basis of the described interactions are as follows:

- simplification of existing systems for preparing OTD for the construction period;
- improving the efficiency of preparation of OTD for the construction period;
- optimization of the use of TP resources;
- establishing a unified framework for continuous improvement of TP performance indicators;
- creation of all necessary conditions for the implementation of activities on planning, monitoring, adjustment of TP;
- increase the ability to adapt to changes in work conditions, requirements of design and working documentation.

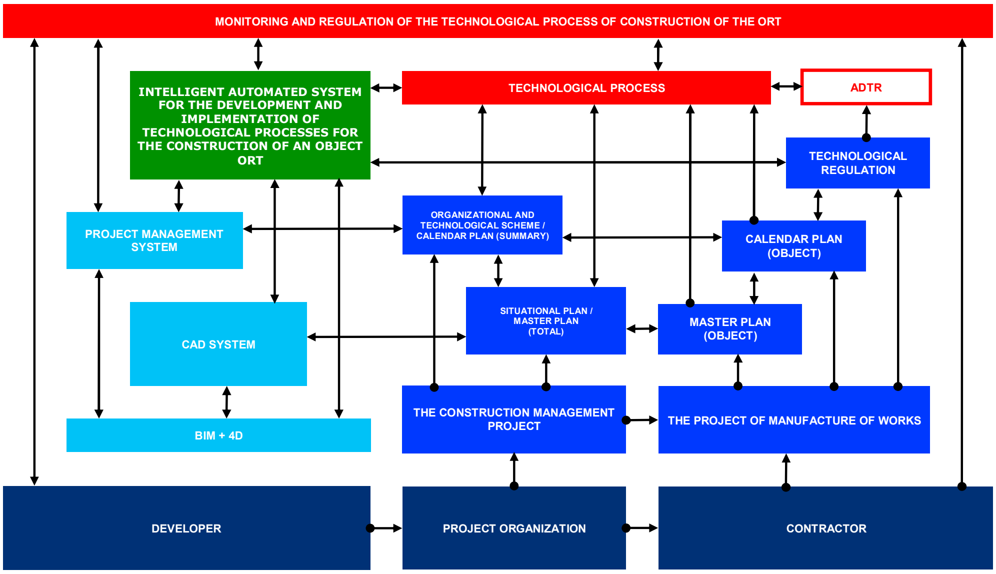

Fig. 5. The place and role of intelligent technologies in the design and construction of railway track objects. Source – author.

At the present stage of creation and development of information technologies in RC, there is a tendency to combine information resources or, in other words, to integrate various information technologies into a single complex.

4. Conclusion

As a result of the conducted research, it is established that a promising direction for improving ITS for RC is intellectualization, which allows organizing the procedure of developing and implementing TP for the construction of RTO in a single information environment. Based on the analysis of modern and promising engineering practices of the development and implementation of TP for the construction of RTO, and the formed structural composition, a structural and information model of the process of functioning of the subsystem of EISTP is proposed.

EISTP is designed to ensure the development and implementation of TP for the construction of RTO at a qualitatively new level. This is achieved through the use of expert and neural network technologies, as well as methods of evolutionary optimization. The expediency of borrowing and developing these areas for solving urgent problems of RC, related to the technological justification of DD of RTO, the definition of the nomenclature of construction works, resource planning, modeling and optimization of TP, the formation of ADTR and technological schemes of work, monitoring and regulation of the technological process is shown.

A conceptual model of IAS has been created to provide intelligent support for the development and implementation of TP for the construction of RTO. The element composition of each of the subsystems of IAS, consisting of modules and databases, is determined. In accordance with the functional tasks of the elements, their internal and external information relationships are identified, on the basis of which the corresponding scheme is drawn up. The use of IAS will allow CCO to quickly develop and regulate TP in order to ensure its own profitability and quality of construction and installation work.

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