Development of Organizational and Technological Schemes of Design of Unique Transport Constructions with Use of Simulation Models

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Abstract. The methodological approach to justification of organizational and technological schemes of design of unique transport constructions with use of simulation models providing a possibility of modeling of work of the design organizations and organizational and technological communications between participants of a designing process taking into account dynamics of receipt of initial information and its uncertainty, an iterativity and lag effect of processes of development of innovative constructive technology solutions, temporary parameters of creation and quality of design developments depending on qualification of designers, engineering risks, etc. stochastic factors is offered. Within the offered approach there are opportunities and according to the solution of problems of increase in efficiency of the design organizations for optimization of terms of development and quality of projects of unique transport constructions: studying impact of automation for terms of development and quality of the developed projects of construction of unique transport objects; development of norms on performance of project works of high complexity; optimization of organizational and technological schemes of design; modeling of risks of timely development of design decisions; determination of the required level of automation of performance of project works; assessment of overall performance of the design organizations for criteria of efficiency, reliability, adaptability, etc.

1. Introduction

The management of design of unique transport objects demands development of alternative options of conceptual technical solutions, application of the non-standard or specially developed methods of calculation of designs and constructive schemes, creation of large-scale models of transport constructions, carrying out additional geodetic and engineering-geological researches, examination at all development stages and accounting of other features and conditions of construction and operation of such constructions. Many of basic data for design have variable, uncertain and non-stationary character. Stochasticity of initial information for development of design decisions, the complexity of the forecast and the loudspeaker of structure of traffic flows, need of development of non-standard technical designs and technological schemes place great demands on qualification of designers, quality of work of the design organizations, timeliness of performance of design tasks [1,2,4,5].

2. Relevance and scientific importance

Despite a significant amount of the researches devoted to increase in effective management of construction of transport constructions, questions of justification of organizational structure, the structure of the design organizations, organizational and technological schemes of their work,
efficiency of application at design of various computer-aided engineering systems and settlement and graphic complexes need carrying out further scientific justifications [6,7,8]. A main objective of scientific research in this direction is development of the methodological approach providing a possibility of modeling of work of the design organizations and organizational and technological communications between participants of a designing process, accounting of dynamics of receipt of initial information and its uncertainty, an iterativnost and lag effect of development of innovative constructive technology solutions, temporary parameters of creation and quality of design developments depending on qualification of designers, engineering risks, etc. [8,9].

In terms of the practical value, official recognition and approbation among the available methods the mathematical models based on network algorithms [2,3,7,14] are most acceptable for achievement of the goals of a research of effective management of construction of unique transport objects. It is caused by the fact that they allow:

- to construct model of a complex system as sets of simple subsystems;
- to make formal procedures for definition of characteristics of system effectiveness;
- to specify the mechanism of interaction of elements of a system for the purpose of the description of the last in terms of its key parameters;
- to find the most effective solutions by optimization of organizational structure and processes of functioning of the design organizations in transport construction.

In the theory of management of road construction the datalogical schemes (DS) as one of types of network models [10,11] are offered. However they are applied in the determined statement and do not allow to consider changes of operating conditions of the design organizations, in particular at design of unique transport constructions.

Probabilistic ILS are necessary for optimization of terms of development and improvement of quality of projects of unique transport constructions. Stochastic representation of work of the design organizations and their structural units (departments and groups) on ILS has to consider at least three aspects: structural, dynamic and stochastic.

The first of them is caused by the number of structural units and organizational and technological communications between them and also between employees in these divisions on hierarchical, technological and functional signs.

The second aspect is defined by qualification of designers and can be considered in usual ILS.

Existence of the third class of stochastic influences is explained by the fact that during development of the project the entering of amendments into basic data for design, tasks and ways of performance of project works depending on these additional researches and also intermediate results and these pilot studies on the scaled model of a unique transport object is possible.

It will demand adjustment or processing of earlier made design decisions at various stages of work of the design organization. In other words, in such situation the return from the subsequent development stages of constructive technology solutions to previous is necessary.

The determined network model (ILS or traditional operation algorithms of the design organizations) reflects process of development of the project only in that ideal case when all stages of work of designers come to an end with positive outcomes and returns on completion (processing) do not happen. Situations of change of dynamics of receipt and updating of basic data for design and return to earlier fulfilled stages (for example, from a bridge footing design stage to an analysis stage of basic data) do not reflect these models. Returns can change considerably topology of the network schedule therefore such concepts as a critical way and reserves, undergo considerable transformation.

The offered simulation model for a designing process of unique transport constructions allows to overcome the specified difficulties, being at the same time further development of ILS.

3. Problem statement

Setting the task of mathematical modeling of work of the design organization for design of unique transport constructions is as follows.
Let there is a design organization, stoked officials (designers, employees) and consisting of the V structural units. Activity of the design organization for performance of project works includes consistent stages (collecting basic data, reconnaissance surveys, the analysis and the forecast of traffic flows, design studies with a necessary volume of engineering survey works, development of ways of introduction of the made decisions, technologies, etc.).

Duration of each $i$-go of a stage ($i=1..., n$) is limited it (is set) by time $\bar{t}_i$. Each $j$-y the employee ($j=1..., m$) is characterized by the level of professional readiness (qualification) $V^j_k$, operating time in a post $\tau_j$ and operating time in this design organization $\tau'_j$, which define quality and the actual period of operation of $j$-go of the expert on $i$-m a stage of performance of project works - $t_{ji}$. The completeness of the design organization by experts can be full or partial. At partial completeness the functions of the left staff (vacancies) are transferred to other performers that leads to increase in $t_{ji}$ of those workers to which functions of left are assigned. In turn, it conducts to additional expenses of time for working off of design stages. When performing project works the situations demanding adjustment or processing of earlier made constructive and technical and technology decisions are possible. The events causing deviations of this sort it is characterized by $P_{te}$ probabilities. Criterion for evaluation of efficiency of the design organization is the probability of development of the project with the required quality in the set time - $P(T_{tTz})$.

4. Theoretical part
The structure of model is rather simple and has block character (fig. 1).

![Structure of a simulation model of work of the design organization.](image)

Apparantly from the drawing, it includes several independent blocks and is based on the modular principle. Blocks 1,2,3,6 can independently be used for the solution of private tasks (calculation of skill level of designers or employees - block 1, modeling of selection of performers and their arrangement on positions - block 2, assessment of efficiency of the design organization without correction of the fulfilled stages of project works - block 3).

The algorithm of modeling includes the following stages:

1. Originally work of the design organization (department, design group) is presented in ILS form - column G ($Id, Ud$) where $Id$ - a set of tops of the count, $Ud$-a set of its arches. Each arch ($i, e$) is
traditionally designated by two events: initial \( i \) and final \( e \) (each event means the beginning or end of a stage of performance of project works, lengths of arches - period of operation of experts at stages).

Constructed columns (the principles of its construction are shown on rice 2.) it will be transformed to a matrix form and it is presented in the matrix form \( T = \begin{bmatrix} \tilde{t}_{ij} \end{bmatrix}_{mn} \) where \( m \)-number of experts; \( n \)-number of stages of work of the design organization, and \( \tilde{t}_{ji} \) - the set period of operation of \( j \)-go of the employee on \( i \)-m a stage.

![Diagram](image)

**Figure 2.** The principles of creation of the network determined model of work of the design organization.

2. For taking note of events (changes of the planned course of performance of the project works) demanding processing or adjustment earlier the made constructive and technical and technology decisions of ILS it will be transformed in the stochastic count with returns. Metodik of creation of such count it is illustrated in figure 3 and consists in the following.
Figure 3. The principles of creation of network model of work of the organization considering returns from the subsequent on the previous design stages.

From a set of tops column \( G \) (\( Id, Ud \)) allocate tops of "b" from where returns are for one reason or another possible. Let’s consider that it is final tops of separate stages of work of the design organization (department, group).

Each of the result of the changes of process of development of the project generating returns can be identified by a return arch \((b, e)\). That is, to each case of return there corresponds the arch connecting a stage of work of the design organization (department, group) from which there was a return, and a stage with which it is necessary to begin processing. In view of the fact that events, defiant returns are non-uniform, not one can proceed from any top of \( b \), and several arches of return on various stages of processing (fig. 4), each of which will have the probability of realization of \( River_{be} \).

\[
(e) \in I_b - \text{ plurality vertices to which return from a vertex } b \text{ is possible} \\
(b, e) - \text{ plurality of returning arc with probability of realization } P_{be}
\]

Return signal:
\( r \leq t, \text{ transient of change of data for design} \)
\( \zeta = P_{be} \text{ - return situation} \)

Statistics for definition of top by it
\[
\{e_1, e_2, \ldots, e_r\} = \left\{ \frac{a_1, a_2, \ldots, a_r}{P_2} \right\}
\]

where \( a_r \) - number of the changes causing returns from top of \( r \);
\( P_2 \) - number of all changes on development of the project coming to structural unit of the design organization.

Figure 4. Structure of a possible complex of returns with flowing on earlier passable design stages.
It is obvious that in a subset of the arches of return proceeding from one top the logical operation "or" in the excluding sense (return is possible only in one top of the count) since the stream of the events causing returns is ordinary.

Thus, formally the columns \( G \) is added by \( \mathcal{D} \) return arches \( \{ (b, e) \} \) will also be transformed to stochastic columns \( G(I_d, U) \), \( U=U \cup \mathcal{D} \{ (b, e) \} \) which depending on the purposes and tasks of its analysis can be integrated it (is aggregated) to necessary level.

To each arch of return \( (b, e) \) column \( G(I_d, U) \) is put in compliance a subgraph \( G_{be} = \Gamma_e \cap \Gamma_b^{-1} \), which arches display the works which are subject to alteration. Here \( \Gamma_e \) - the count to whose tops it is possible to get, moving from an event in the direction of arches, \( \Gamma_b^{-1} \) - the count to whose tops it is possible to get, moving from "b" on arches with the return orientation.

Distinctive feature considered the column is performance of the works entering in columns \( G \) which correspond to the determined arches, and some of works because of returns can repeatedly be carried out. Repeated works on the contents and expenses of time can change, for example because changes of the course of performance of project works and basic data are insignificant or the performer uses initial information for specification of the design decision.

3. By means of block 1, numerical values of indicators of qualification of designers are modelled. The mechanism of modeling of these indicators is described in work [13].

As a result of one realization \( UK \) vector = turns out \( Y^k_j \) dimensions of \( m \) which components are skill levels of designers. At autonomous use of the block the empirical function of distribution of a random variable is result of modeling \( Y^k_j = F(Y^k_j) \), which gives the chance of forecasting of quality of work of experts in the design organization.

4. If necessary (for example, at selection of performers, formation of design groups, a research of overall performance of departments or the design organization in general), arrangement of experts to positions (block 2) is modelled. The problem is solved with use of the known mathematical model of linear programming – tasks about appointments [12]. Output information is presented in the form of a matrix of appointments \( X = [x_{ji}] \).

5. The actual working hours of designers at development stages pf projects are defined \( \bar{t}_j \) by accounting of indicators \( Y^k_j \) (block 3). Results of calculations are brought in a matrix \( T = [t_{ji}] \), i.e. to values \( \bar{t}_j \) values \( t \) are appropriated \( \bar{t}_j \) and the general time of vypolneniaproektyno works without their adjustment which is is defined

\[
T_{\bar{t}_j} = t_{i1} + t_{i2} + ... + ti + ... + tn ,
\]

where \( ti \)-maximum time of realization of i-go of a stage of performance of project works, at the same time

\[
ti = \max\{ t_{ji} \} .
\]

6. The revoltting influences reflecting dynamics of development of design decisions and possible changes of basic data and the predicted intermediate results are generated (changes of the planned course of design generate returns from flowing on earlier passable stages).

As the simulator of external influences serves block 4. The main property of information - baht by display of material processes is the basis for modeling of this class of factors. Data carriers are the results of pilot studies and change of initial information arriving in a designing process. It is obvious that the nature of return (quantity of the stages which are subject to processing) depends on contents of the arriving information and the moment of its receipt. According to it the block of imitation of changes of the course of performance of project works is divided into two modules: the module of
imitation of discrete time of receipt of information and the module of imitation of a stage with which it is necessary to begin processing.

The procedure of modeling of size of intervals of time between receipts of information is organized by means of a method of inverse functions on dependence

$$
\tau_i^0 = -\frac{1}{\lambda} \ln \xi_i,
$$

(3)

where \( \xi_i \) - evenly distributed number in the range of \((0,1)\);

\( \lambda \) - intensity of receipt of messages (information of the demanding correction of the fulfilled project stages).

Thus, the information message coming to the design organization is generated (department, group or to the certain performer in timepoint of \( t + \tau_i^0 \)) (\( t \) - corresponds to the current time of performance of project works).

The procedure of modeling of a stage with which it is necessary to begin processing according to the arrived information consists in definition of its number. To this number the value of the discrete random variable set by statistics is put in compliance:

$$
\left( e_1, e_2, \cdots, e_n \right),
$$

$$
\left( P_{be_1}, P_{be_2}, \cdots, P_{be_n} \right).
$$

Numerical value \( P_{be_i} \) - is defined by a frequency of receipt of information of \( i \)-go of a look causing return on \( i \)-y a stage.

Considering that information on changes of basic data for design comes to the design organization (department, group or to the certain performer) by means of information messages and believing receipt of each of them as equiprobable events and also considering that statistics of such messages is available, it is possible to define (to predict) \( P_{ie} \) for all tops of \( bi \in \{b\} \).

So

$$
P_{ie} = \frac{a_{ie}}{A},
$$

(4)

where \( a_{ie} \) is number of the information messages causing return from \( biv \) top top \( "e" \);

\( A \) - number of all information messages coming to the design organization.

Special explanation is demanded by the mechanism of a draw of returns.

Let from top of \( bi \) there is a possibility of return to the previous stages \( e1, e2... EC,.., en \). \( P_{be_k} \) - there is a return probability from an event of \( EC \).

The procedure of modeling of return is carried out with use of "the standard mechanism of a draw" of a single lot according to which to top of \( bi \) the sequence of \([0,1]\) random variables which are evenly distributed on a piece is put in compliance \( \zeta_1^b, \zeta_2^b, \cdots, \zeta_n^b \). When performing a condition \( \zeta_1^b \leq \zeta_2^b \leq \zeta_3^b \leq \zeta_n^b \) there is a return to top of \( EC \).

The mechanism of modeling is very simple. Evenly distributed number is generated \( \zeta \in [0,1] \) also the interval of \( v+1 \) to which this number got from a condition is defined:

$$
\sum_{k=0}^{v} P_{ie_k} \leq \zeta \leq \sum_{k=0}^{v+1} P_{ie_k}, \quad v = 0, \ldots, s + 1.
$$
For uniformity of record it is accepted $P_{ie_0} = 0$, $P_{ie_{i+1}} = q_b$ (here $q_b = 1 - \sum_{k=1}^{s} P_{ie_k}$ there is a probability not to return, and to pass from $b$ event $i$ in $b$ event $i+1$. It is obvious that at such procedure only one arch to which there corresponds probability is implemented $P_{be_{i+1}}$).

As a result of single modeling we receive private realization of the stochastic count - determined columns $G_d$ representing some probabilistic copy of functioning of the design organization (department, group).

7. The algorithm of calculation of temporary characteristics of work of the design organization is reproduced (department, group).

Computing procedure $T_f$ is under construction on formation of line $R$ characterizing the sequence and frequency rate of performance of the stages $R= (R_1, R_2, ..., R_n)$, where $R_i = \begin{pmatrix} i \\ k_i \end{pmatrix}$ - a two-dimensional vector column at which the first a component represents number of a stage, and the second its current frequency rate.

Starting with the analysis of basic data, the subsequent stages of work of the design organization are carried out consistently (as well as in the determined ILS) and the frequency rate of $k=1$ is attributed to them, i.e. the line has an appearance

$\begin{pmatrix} 1 \\ 1 \\ 2 \\ 1 \\ 3 \\ 1 \\ \vdots \\ \vdots \end{pmatrix}$

Process of performance of project works continues monotonously before receiving the first signal of return. Let at the stage "b" the signal to return to the stage "e" where $e < b$, then is appropriated to an event of frequency rate of $k=2$ and a line on this step be received looks so

$\begin{pmatrix} 1 \\ 1 \\ 2 \\ 1 \\ e \\ 2 \\ b \end{pmatrix}$

Further the realization of a subgraph from the beginning in "e" with assignment to repeatedly passable tops of frequency rate of $k=2$ is enabled. Process continues before receiving the following signal of return.

As a result line $R$ gives complete idea of the sequence and frequency rate of performance of each stage of project works and allows to calculate operation parameters of the design organization (time of working off of stages of the project).

$$T_{\phi} = \sum_{i=1}^{n} \left( t_i + t_i \sum_{\eta=1}^{k_i-1} r_\eta \right), \quad (5)$$

where $t_i$ is time of performance of $i$-go of a stage of performance of project works; $k_i$ - frequency rate of performance of $i$-go of a stage; $r_\eta$ - coefficient of change of the $t_i$ parameter at repeated performance of a stage $\left( 0 < r_\eta \leq 1 \right)$.

Size $r_\eta$ is accidental and is defined in the assumption of uniformity of its distribution by modeling on a half-interval $(0,1]$.

8. The trial number of realization of the Wpr model ($Wpr = 50...100$) and check of reliability of temporary parameters of model is made ($T_{\phi}^0, T_{\phi}^{mi}$) (blocks 5,6). At unsatisfactory estimates (confidential probability of $Rd < 0.95$) the necessary number of tests of $Wi$ is determined $W$-fold modeling is carried out.
5. Practical importance
Unlike the existing, offered approach to a research of overall performance of the design organizations, their structural units and certain designers allows to apply nutrition, to pick up employees and to determine the required performance terms of project works taking into account the number of staff and equipment by the modern systems of computer design and the equipment for experimental works.

Within this model there are opportunities and according to the solution of other problems of increase in efficiency of the design organizations for optimization of terms of development and quality of projects of unique transport constructions: studying impact of automation for terms of development and quality of the developed projects of construction of unique transport objects; development of norms on performance of project works of high complexity; optimization of organizational and technological schemes of design; modeling of risks of timely development of design decisions; determination of the required level of automation of performance of project works; assessment of overall performance of the design organizations for criteria of efficiency, reliability, adaptability, etc.

6. Conclusions
Imitating modeling in problems of justification of organizational and technological schemes of design of unique transport constructions provides a possibility of modeling of work of the design organizations taking into account dynamics of receipt and the stochastic nature of initial information, innovative constructive technology solutions, temporary parameters of creation and quality of design developments depending on qualification of designers, engineering risks, etc. factors. The problem of increase in efficiency of transport design demands carrying out further theoretical and pilot studies in the field of reduction of terms of design and building to a basis of simulation models of work of the design organizations, introductions of methods of conceptual design and information modeling of transport objects. It will allow to reduce quantity of mistakes in the project documentation, caused by uncertainty of basic data, to determine terms of development of the project, to reduce risks of discrepancy of the project with real service conditions of a transport object, to execute requirements to ensuring transport safety of objects of transport infrastructure at stages of their design, construction and operation.

References
[1] Bagrinovsky K A 1990 Imitating modeling in problems of planning and management of economy: [Sb. article] Academy of Sciences of the USSR, Center.econ. - a mat. in-t (M.: CEMI) 220 p
[2] Mironosetsky N B, Kirina L V etc 1988 Models of management of scientific and technical progress at the enterprise (Novosibirsk: "Science") 152 p
[3] Astanina L A, Kirina L V 2013 About one approach to accounting of external changes at project management Improvement of institutional mechanisms of management in industrial corporations: sb. nauch. tr. under the editorship of V V Titov, V D Markova IEOPP of the Siberian Branch of the Russian Academy of Science (Novosibirsk) pp 227-234
[4] Batting N I, Kolosova N B, Berdyugin I A 2013 Efficiency of application of systems of automatic control of accugrade in construction Construction of unique buildings and constructions 4(9) pp 29-35
[5] Kalashnikov A A, Vatin N I, Kalashnikov A A, Vatin N I 2010 The organization and planning in construction. Management of construction projects M-in science and education of the Russian Federation, the St. Petersburg state. polytechnical un-t. (St. Petersburg)
[6] Bondareva E D, Klekovkina L S 2017 Researches and design of highways (Moscow) 11 Universities of Russia (the 2nd prod., ispr. and top)
[7] Bolotin S A, Vikhrov A N, Glady N Ya 2008 The analysis of inopportuneness of performance of work from a position of the theory of nonlinear dynamic systems Malkin of M/messenger of civil engineers 1 pp 33-38
[8] Ermoshin N A, Lazarev Yu G, Egoshin A M, Dragons A T 2017 Management of investment and technical risks in road construction (Monography) MAOL is SPb: LLC R-COPY 210 p
[9] Ermoshin N A 2012 Design of production structure of the road-building organizations taking into account uncertainty of structure-forming factors (M.: ROSDORNIYA’S federal state unitary enterprise) Collection “Roads and Bridges” issue 27 pp 32-41
[10] Maltsev Yu A 2010 Economic-mathematical design methods of transport constructions: the textbook for student Publishing center “Akademiya” 320 p
[11] Maltsev Yu A 2015 Bases of scientific research: textbook (M.: Balashikha) VTU 310
[12] Taha H 1985 Introduction to a research of operations: in 2 books Prince Transl. from English (M.: World) 479 p
[13] Ermoshin N A, Serbian A V 2013 Metodik of assessment of the impact of qualification of the worker for the period of performance of military and scientific tasks Collection of academy 56(08) (SPb.: WATT) 322 pp 123-128
[14] Masur I I etc 2009 Project management under a general edition of I I Masur and V D Shapiro the 5th prod. reslave (M.: Omega-L publishing house) 960 p