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Diagnostics of Projects

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Abstract:

The importance of the problem under investigation is to find an effective way to manage the defaults occurred in case of a project which has not enough control during the process of implementation. Usually it goes to delays, and as a consequence to it in very poor quality.

The purpose of the article is to provide the project with the necessary level of control by placing control points in it. The article suggests methods for determining the places and necessity for conducting inspections during the construction period of the project.

The materials of the article can be used by project managers for more efficient and qualitative management, for faster completion with the lowest possible cost in the highest possible quality.

Keywords: *Control point, project validation, project management.*

JEL Codes: *O22.*

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1. Introduction

Any project consists of the works performed in the particular logical sequence. Each work has to have the result meeting the established requirements. If though – one of these requirements is not met, then work is performed with a mistake. In particular, if the result of such work is an element of technical system, then it is possible to say that faulty or even disabled element is result of work. If mistakes in works are revealed only at the stage of verification of the finished products to the established requirements, then a lot of time for their localization will be required. Time of the project can be overdrawn (Zuykov, 2012; 2015). The strategy of well-timed detection of mistakes in works of the project at which each of works is checked for compliance to the major parameters (partial check) is expedient, and the complete checks are carried out after some works (PMBOK). We will call such checks control points.

Emergence of mistakes when working the project should be classified as the negative risk. Localization of these mistakes by control points is a method of decreasing the influence of risk on a result of the project. For each large project there is a huge number of possible sets of control points. The rational choice of the control points is one of the most important problems of diagnostics of projects (Williams, 1995). Development of methods of the choice of the control points is the relevant theoretical task having great practical value for efficient management of projects (Taylor, 2016). The present article is devoted to this problem.

2. Methodological Framework

2.1 Problem definition

Mathematical problem definition of the choice of the control points in the project can be formulated as: There is a project consisting of $\mathbf{n}$ works. Duration of work $\mathbf{i}$ is equal to $\mathbf{t_i}$. The project network is given. There can be mistakes during performing the project. Several mistakes are possible. If after realization of the latest work of the project it is revealed that mistakes took place, then it is necessary to carry out searching of the works performed with mistakes and, at least, to repair them, and it is common to redo all those works which uses results of the works performed with mistakes (Bondarenko *et al.*, 2017.

As a result, the project will be detained for the period of diagnostics and restoring a rightness of realization. Let's call further it *"a delay time of the project completeness"*. Failure to meet time constraints of the project causes financial losses. These losses linearly depend on a delay time of the project completeness (Leus, Herroelen, 2004). The delay time of the project completeness is a random value. Its values will be various at various sets of mistakes. For decrease of this time it is possible to carry out the intermediate complete checks after completion of works.

With their help mistakes can be defined earlier, then at final check of result of the project. Duration of the complete check after work of **j** is equal to $\mathbf{T_j}$.

It is required to define how many intermediate checks (check points) to do and after what works? The solution of this task requires the following:

• Probability model of appearance of mistakes in the works of the project;
• Model of restoring process for correct project implementation and model of the project as subject of the diagnosis (Grachyov, 2013; Dzhukha *et al.*, 2017).

The probability model of appearance of mistakes in works of the project allowing to calculate probabilities of mistakes in several works is offered by the author (Maron, 2016). Furthermore the model of restoring process for correct project implementation and model of the project as subject of the diagnosis (Herroelen, Leus, 2010).

2.2 Model of model of restoring process for correct project implementation and model of the project as subject of the diagnosis

Let's consider projects for which the following condition is satisfied. If work of **A** is a predecessor of work **B**, then the result of work of **A** is used for obtaining result of work of **B**. Let's call the projects having such property projects with the works connected by results (WCR). Let's notice that in the classical mathematical model of the project developed in the fifties in the last century and used until now the concept of result is absent (Sakka *et al.*, 2016). This concept was legibly recorded in the IDEF0 standard which arose later and is intended for the description business – processes. According to this standard the Output (the result) is obligatory attribute of work. According to IDEF0 if the result of work of **A** is an entrance of work of **B**, then this result is processed (changes) for obtaining result of work of **B**. Let's understand quite so further communication by results between works of the project (Vrhovec, 2015). At the same time the following standard options different by the form restoring algorithms are possible.

Option 1 is characteristic of the program complexes creation projects consisting of the separate modules realizing the methods put in them when which developing methods of object-oriented programming are strictly kept (Lyneis *et al.,* 2001). In this case, the situation when work of **B**, transforms result of work of **A** is possible and though its result will be the exact only if it and work of **A** are executed without mistakes, but work of **B** there is no need to remake if in the previous work of **A** the error is noticed. In this case it is quite admissible that the rational algorithm of restoring will consist of checks of works, and of operations on their reworking.

Option 2 is more common - work of **B** cannot be performed correctly if it is based on the irregular result of the previous work **A** and for restoring of a correct project implementation it should be remade. An example – the Apartment renovation project in which work **A** consists of alignment of a wall, and work **B** of gluing of wall-paper. If walls are not leveled (a mistake when performing work **A**), then even if wall-paper will be pasted correctly, work **B** all the same should be redone, after correction of a mistake (reworking of work of **A**). And on reworking of work of **B**, more time will be spent, than it was planned initially - the pasted wall-paper should be unhung (Abdel-Hamid, 1984).

Let's give another example. Assessment of the Commercial Real Estate project. Cooperative work **A** – determination of parameters of the estimated object. Work **B** calculation of cost. If at least one of parameters of the estimated object of the commercial real estate is determined wrongly, that is the mistake in one of the works entering cooperative work **A** will be made, then calculation of cost will be insecure, and in that case when it is carried out in due form. After elimination of the made mistake calculation has to be carried out anew, and it will borrow as much time as it was taken initially. We will call such projects as the projects with works strongly – connected by results (WSCR).

Let's pass to model building of the project as subject of the diagnosis, the correctness of project implementation and searching of possible mistakes intended for problem solving of monitoring. At the same time, we will be limited to consideration of projects with works strongly – connected by results. The model of a subject of the diagnosis has to give the chance to uniquely determinate result of any admissible check at any its possible state. The following model is offered.

Definition: The Diagnostic Model of the Project (DMP) is a form of representation of accordance between mistakes in works of the project and results of the complete checks of works. The project is submitted as the network where nodes represent works, and edge, not only logical communications between works, but also places of realization of possible complete checks (Futrell *et al.*, 2002). At the same time the complete check of work **j** has a positive result then only when mistakes are absent in this work and all works with it previous. Otherwise this check has the negative result.

The positive result - π_1^j of the check Π^j in work **j** is a result at which established that all parameters of result of this work conform to the established requirements. The negative result - π_0^j of the check - Π^j in work **j** shows that at least one parameter of result of this work does not conform to the established requirements. Reasons for the negative result of the check can be mistake in work **j** or mistakes in works precede to it. Precede works are understood as all works lying on the ways from initial works – initial node of the network to this.

The offered model allows to use the known methods and algorithms of the graph theory to construct the table in which for each check its result will be specified at everyone the possible condition of the project characterized by existence or lack of mistakes in works. By analogy with the table of possible malfunctions of technical system, we will call such table the table of possible errors of the project.

Using given concepts of the table of possible errors of the project and project with works strongly - connected by results it is possible to calculate duration of restoring a correctness of the project implementation at any combination of check results in control points. It will be used in the objective method of solution offered below.

3. Results

3.1 Method of solution

The following method of solution of an objective is offered:
1. To define check which entropy of result is maximum;
2. To define whether mean time of diagnostics and restoring a correctness of project implementation reduces by its realization;
3. If does not reduce, then to stop further searching of checks which are expedient for carrying out. If reduces, then to accept it as check which is expedient for executing and to pass to point 1 taking into account earlier found checks.

For calculation of an entropy of result of checks and mean time of diagnostics and restoring a correctness of project implementation it is necessary to know probabilities of appearance of the mistakes in works. They can be calculated on the basis of the model offered in work (Maron and Maron, 2012).

3.2 Example

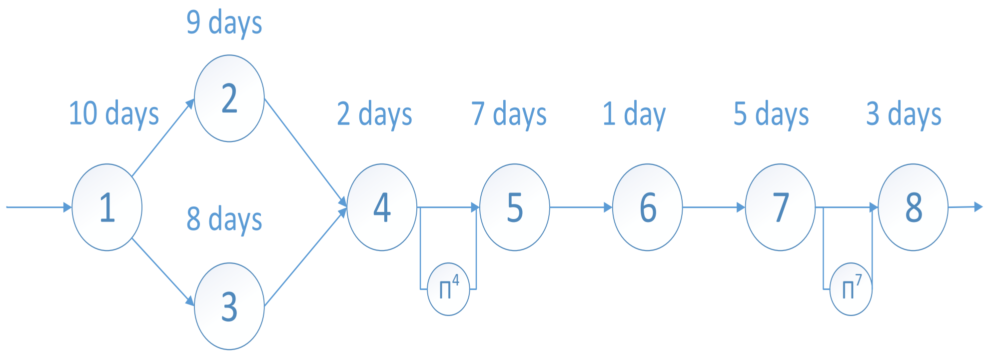
Let's consider the WSCR project which network is provided on the Figure 1. Planned duration of works in days are specified in the drawing. Let's assume that duration of restoration of work is equal to its planned duration, and duration of each check – 2,5 days. Let's say that the project is standard and from the previous experience of realization it is known that 30% of similar projects are carried out without mistakes. After completion of the latest work of the project check is surely carried out. It is considered in the project plan.

Let's define what intermediate checks expediently to execute, or in other words what control points it is expedient to plan for this project to reduce mean time of a delay of completion of the project. The possibility of existence of mistakes in works of the project is the reason of a delay. For this purpose, we will apply the offered method. Let's begin with calculation of probabilities of various conditions of the project as subject of the diagnosis. In work (Maron, 2016) the model of appearance of mistakes in works of the project is offered. According to this model, the performed works are affected by Poisson flow of mistakes. The interval of action is equal to **-** a total time of all works – sum of $\mathbf{t_i}$ on **i** from 1 to **n**. The intensity of a stream of mistakes (a median number of the mistakes arising in unit of time) can be found on a formula.

$$\lambda = -\frac{\ln P_0}{\tau} \tag{1}$$

Where:
$\mathbf{P_0}$ is the probability that there are no mistakes in the project.
For the reviewed example: $\mathbf{P_0 = 0{,}3;\ \tau = 45[days];\ \lambda = 0{,}027\ [1/day]}$.

Figure 1. *An example of the choice of control points in the project*



Let's execute calculation of an entropy of result of each admissible check. Results of calculation are given in Table 1.

Table 1. *Results of calculating an entropy of checks.*

Control point	$P(\pi_1^j)$	$P(\pi_0^j)$	$H(\Pi^j)$[nit]
Π^1	0,765	0,235	0,545
Π^2	0,601	0,399	0,672
Π^3	0,618	0,382	0,665
$\mathbf{\Pi^4}$	0,460	0,540	**0,690**
Π^5	0,382	0,618	0,665
Π^6	0,372	0,628	0,660
Π^7	0,325	0,675	0,631

The entropy of result of check $\mathbf{\Pi^4}$ is maximum. This check will give a maximum of information on a condition of the project. At the qualitative level it is easy to explain why check which result has the maximal indeterminacy is most informative. Check - an experiment. The maximum of information yields result of an experiment which initially was least of all predictable. Within an information theory of Shannon this fact can be proved strictly. The entropy of result of check Π^4 was calculated as follows. This check will have a positive result if each of works { 1; 2; 3; 4 } will be executed correctly – without mistake. The probability of such event is defined by expression:

$$P(\pi_1^4) = \exp(-\lambda * (t_1 + t_2 + t_3 + t_4)) = \exp(-0,027 * 29) \approx 0,460$$

The probability of the negative result - $P(\pi_0^4)$ supplements this size to unit and is equal to **0,54**.

Respectively, the entropy is defined by expression

$$H(\Pi^4) = -P(\pi_1^4) ln P(\pi_1^4) - P(\pi_0^4) ln P(\pi_0^4) = -0,46 ln 0,46 - 0,54 ln 0,54 = 0,69[nit]$$

Entropies of results of other checks are similarly calculated. Now, according to point 2 from offered method, we will define whether mean time of restoring a correctness of the project implementation will be reduced by realization of check Π^4. The following strategy are possible:

A_1 - not to execute check Π^4;
A_2 – to execute check Π^4.

To each of them there corresponds the delay time of the termination of the project which depends on what of possible states will arise in the course of implementation of the project. On a restoring time of a correctness of the project implementation the following four states are in essence various:

S_{00} – mistakes will not be in works {1; 2; 3; 4} and in works {5; 6; 7; 8};
S_{01} – mistakes will not be in works {1; 2; 3; 4} but will be in works {5; 6; 7; 8};
S_{10} – mistakes will be in works {1; 2; 3; 4} and will not be in works {5; 6; 7; 8};
S_{11} – mistakes will be in works {1; 2; 3; 4} as well as in works {5; 6; 7; 8}.

Probabilities of states and values of a restoring time of a correcnes of the project implementation corresponding to them are provided in Table 2.

Table 2. *Possible states of the project after first control point.*

State	S_{00}	S_{01}	S_{10}	S_{11}	
Probability	0,3	0,160	0,352	0,188	
Strategy	Time of returning correctness in the project				Mean time
A_{11}	0	45	45	45	31,5
A_{12}	2,5	18,5	31,5	47,5	23,7

The state probability of $\mathbf{S_{00}}$ is equal initially to the given probability of the exact implementation of the project. At strategy $\mathbf{A_{11}}$ in this case the delay of the termination of the project will not be. At strategy $\mathbf{A_{12}}$ there is a delay time of the termination of the project for the period of **T = 2,5 days** which will be spent for realization of check $\mathbf{\Pi^4}$. The state probability of $\mathbf{S_{01}}$ is equal to the work of probabilities of casual events:

"There are no mistakes in works {1; 2; 3; 4}";
"Mistakes are in works {5; 6; 7; 8}".

It can be calculated as follows:

$$\mathbf{P(S_{01}) = exp(-\lambda(t_1 + t_2 + t_3 + t_4))\,(1 - exp(-\lambda(t_5 + t_6 + t_7 + t_8)) = 0,160}.$$

If this state arises, then when performing check $\mathbf{\Pi^4}$, the positive result will be received. Then, works {5; 6; 7; 8} will be performed. After completion of the last – the eighth work of the project – check which will have the negative result will be executed. Respectively, at strategy $\mathbf{A_{12}}$ it is necessary to redo only works: 5; 6; 7; 8. A delay of the termination of the project we will consist in this case of their cooperative duration and a run time of check $\mathbf{\Pi^4}$ and will make 18,5 days. Let's remind that check after work 8 is obligatory and its time is considered in the planned duration of the project. If to accept strategy $\mathbf{A_{11}}$, then the delay time of the termination of the project for this state will be equal to **τ=45[days].**

Similarly, there are probabilities of states and values of a delay time of the termination of the project corresponding to them at the specified strategy. To strategy $\mathbf{A_{12}}$ there corresponds smaller mean time of a delay of the termination of the project. Therefore, check $\mathbf{\Pi^4}$ should be executed.

Let's define whether it is expedient to carry out the intermediate checks still. Values of an entropy of results of checks which can be executed considering that check of $\mathbf{\Pi^4}$ will be executed are given in Table 3. Check of $\mathbf{\Pi^7}$ has the maximal entropy of result.

Table 3. *Results of calculating an entropy of checks after first control point.*

Control point	$P(\pi_1^j)$	$P(\pi_0^j)$	$\mathbf{H(\Pi^j)[nit]}$
$\mathbf{\Pi^5}$	0,829	0,171	0,457
$\mathbf{\Pi^6}$	0,807	0,193	0,490
$\mathbf{\Pi^7}$	0,706	0,294	**0,605**

Here it is necessary to pay an attention to the following. Existence or lack of mistakes in works {1; 2; 3; 4} which will be revealed by check $\mathbf{\Pi^4}$, does not influence probabilities of emergence of mistakes when working in any way {5; 6; 7; 8}. The intensity of a stream of mistakes does not change! Respectively, the probability of a positive result of check **Π^7** is calculated just as earlier the probability of a positive result of check **Π^4** was calculated:

$$P(\pi_1^7) = \exp(-\lambda * (t_5 + t_6 + t_7)) = \exp(-0,027 * 13) \approx 0,706$$

The probability of the negative result - $P(\pi_0^7)$supplements this size to 1. Probabilities of results of other checks are similarly calculated. Then, the entropies corresponding to them pay off. Now it is necessary to define whether mean time of a delay of the project will be reduced by realization of check **Π^7** provided that to it check of **Π^4** will be executed.

Checks **Π^4** and **Π^7** break works of the project into three groups: {1; 2; 3; 4}; {5; 6; 7}; {8}. However, when performing check **Π^7** it is possible to be sure that in works {1; 2; 3; 4} there are no mistakes. Really, the result of check of **Π^4** will show there were mistakes at their realization or not. If mistakes were, then they will be eliminated. Therefore, as well as earlier, it is enough to consider four possible states:

S_{000} – There is no mistakes;
S_{001} – a mistake in work {8};
S_{010} – mistakes in group {5; 6; 7};
S_{011} – mistakes are in group of works {5; 6; 7}, and in work {8};
and two competing strategy:
A_{21} – to carry out check **Π^7**;
A_{22} – not to carry out check **Π^7**;

Probabilities of states and values of a restoring time of a correctness of the project implementation corresponding to them are provided in Table 4.

Table 4. *Possible states of project with 2 check points.*

State	S_{000}	S_{001}	S_{010}	S_{011}	
Probability	0,652	0,054	0,271	0,023	
Strategy	Time of returning correctness in the project				Mean
A_{21}	0	16	16	16	5,6
A_{22}	2,5	5,5	15,5	18,5	6,6

The state probability of **S_{000}** is the conditional probability. It shows probability that mistakes by the time of the termination of the project will not be provided that among works {1; 2; 3; 4} there are no mistakes. It is not equal to **P_0**, and is calculated on a formula:

$$P(S_{000}) = \exp(-\lambda(t_5 + t_6 + t_7 + t_8)) = 0,652$$

Apparently from the data provided in table 4. Realization of check **Π^7** will not reduce mean time of a delay of the project. Therefore, we conclude that at implementation of this project it is necessary to execute one intermediate check **- Π^4**. The task is solved.

4. Discussion

In the majority of works in the field of projects management diagnostics of projects is understood as definition of the indexes allowing to establish that there was a deviation from the basic plan demanding rescheduling or adoption of other administrative decisions. Calculation of reference indexes of a deviation for cost and time is realized in MS – Project and other time schedule controls by projects which it is possible to consider CASE – the tools corresponding to PMBoK. Relatives on the purposes to such works are articles devoted to stability of projects. In them the indexes, methods and algorithms allowing to define the moment when in the project there were already so serious deviations that it cannot be executed with the given restrictions on time and cost which are offered.

Other direction of researches which was analyzed on a possibility of application, the methods offered in them, for the solution of the considered problem are the works devoted to ensuring quality in projects. Here the closest on subject can consider article in which the method of definition of works which results should be controlled on compliance on quality in a prime order is offered (Mindlin, 2013). This method is as follows. The list of all **n** of works of the project is formed. If it is decided to carry out monitoring of results of **m** from them regarding compliance to requirements for quality, then selection parameter is chosen: duration, labor input or cost. Works are ordered in this parameter and for monitoring the first **m** of works get out of the ordered list. If to apply similar approach to the choice of control points for the purpose of localization of mistakes, then information put in logical communications between works will be obviously lost.

To questions of decrease in probabilities of risks in general and mistakes, at implementation of projects, in particular it is devoted much more works, than a problem of decrease in consequences of their realization. It is bound to the fact that for decrease in probabilities of risks organizational measures which offer and the analysis is dominating the direction in works on project management are applied, first of all. Are the most significant for the solution of a problem of the choice of control points the following known result:

"An efficient method of decrease in probability of emergence of mistakes when working is functional inspection".

Functional inspection is applied when the responsible product has to become result of the project special, or as it is accepted to speak in defensive branch, a product. Let's give an example. The project is directed to creation of especially responsible product. One of stages of the project is its assembly. Till its beginning the detailed instruction for assembly is developed. Three experts participate in realization of work on assembly. One reads point of the instruction devoted to the next operation. The second expert carries out operation. The third checks a rightness of its realization. In practice, functional inspection is applied only at implementation of especially responsible projects (ERP) because demands the considerable expenses of life and material capabilities.

About the direction in diagnostics of projects which subject is the choice of checks for monitoring of a regularity of implementation of the project and searching of the works performed with mistakes for the first time it is written in works of the author (Maron and Maron, 2010; 2012).

In the work of (Maron and Maron 2012) the method of allocating control points in ERP was for the first time offered. The method was based on calculation of an entropy of checks on Shannon. Such arrangement of control points at which maximal time of searching of irregularly performed work is minimum was considered as optimum. On the basis of a simulation modeling it is established that offered in work (Jahangirian, 2010) heuristic approach yields result, the close to optimum. In this method the dependence between results of works of the project is considered.

Restriction of a method was the assumption of lack of the multiple mistakes – mistakes in several works of the project which is fair if functional inspection is carried out for all works of the project. Respectively, probabilities of mistakes in works reckoned as linear connected with their planned durations. Besides, it was supposed that time of check can be neglected because rapid growth of losses from a project delay time is characteristic of ERP. In the work of (Maron 2016) informational approach to definition of control points was extended to projects at which implementation there can be various scenarios. At the same time the assumptions stated above remained.

Therefore, a method range of application (Maron, 2015), as well as a method (Maron and Maron, 2012), is the choice of control points in ERP when which performing all works functional inspection is applied. In this article the method of the choice of control points in the project for more general case when it is impossible to neglect existence of mistakes in several works of the project, check duration in a control point is offered.

5. Conclusion

Based on this research the following conclusions have been drawn:

1. In this work diagnostics of projects is understood as the choice of control points for validation of performance of work;

2. The rational choice of quantity and the locations of control points allows to reduce significantly risk of failure to meet time constraints of the project because of mistakes at its realization;
3. The method of determination of quantity and the locations of control points which can be applied to the majority of standard projects is for the first time offered.

Unlike earlier developed methods (Maron and Maron, 2012; Maron, 2015) it is considered as a possibility of existence of mistakes in several works, and expenses of time for realizations of operations of monitoring.

6. Recommendations

The above results are of great value for project managers. The offered method of the choice of control points should be applied when scheduling the project. The author developed a program complex which realizes the offered method in relation to the projects planned in MS – Project.

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