Dynamic Correction of the Construction Projects Scheduling Implementation under Stochastic Influences

M G Dobrosotskikh¹, V Ya Mishchenko¹, A V Mishchenko¹

¹ Department of Technology, Organization of Construction, Examination and Management of the real estate, Voronezh State Technical University, 20-letija Oktyabrya str, 84, Voronezh, 394006, Russia

E-mail: dobrmax@yandex.ru

Abstract. The research results of this paper show that parameters of the catch-up schedule are determined by the dynamics of time-averaged volumes, rates and accelerations of construction jobs only when discrete nature of resources consumed has a weak influence on the rate of project jobs. On the other hand, if the speed of job is determined by the use of nonstockable resources, the dynamics of jobs volume demonstrates the weak sensitivity both to the discrete nature of resources and to external stochastic influences. In this, the speed and acceleration of jobs experience jumps at the times of changes in the number of resources used. Thus, a time-averaging operation leads to the loss of information about these features of construction dynamics. In this paper the algorithms for stochastic factors accounting (characterized by different influences on the project implementation) are formulated. Moreover, the algorithm for forming the catch-up jobs schedule is obtained based on the results of monitoring of the jobs pace and averaging only over periods of a constant composition of a number of discrete resources. Furthermore, both empirical methods of separation of stochastic and deterministic impacts on the project implementation, as well as a method based on the qualitative difference in the Fourier spectra of stochastic and deterministic functions, have been developed. The limits of applicability of the empirical and exact methods are analyzed. It is shown that the Fourier analysis of the monitoring results allows to completely recover the deterministic information even against the background of the stochastic signal that coincides with it. It is shown that the proposed algorithm makes the formulation of catch-up jobs scheduling parameters possible, allowing to avoid financial and image losses associated with the untimely end of the project or its main parts.

1. Introduction

In the national [1] and global [2] practice of construction projects implementation the flow line method of scheduling is in widespread, which is determined by a number of inherent advantages. So, in particular, the flow line method ensures the even consumption of resources, the rhythm of finished product production, creating the favorable conditions for allied organizations jobs: contractors, factories, transport enterprises. However, the use of this method is limited by the need to organize equirhythmic or multirhythmic flows components, which is rarely achievable in practice [3]. Besides this, some difficulties were encountered in the practical use of flow line methods, which are determined by the contradictions between the hard labor specialization and the constant change in the ratio of volumes of various types of jobs, related to the dynamic change of construction objects [4].
The practical applicability of this approach is also limited by the instability of the flow processes with the respect to external stochastic influences [5, 6].

A significant drawback of the flow line scheduling method (which does not allow for system optimization) - is the iterative nature of accounting for resource constraints. In this formulation, at the first stage, the resources are considered unlimited and the required resources (in accordance with the project documentation) are calculated by the criterion of the project duration. Next, the construction scheduling is adjusted both in terms of jobs performance and in terms of resources attracted at each construction operation stage. At the same time, as indicated in [2], due to the large range of resources taken into account, the adjustment of this criterion is an extremely difficult task. Therefore, the real process of scheduling design is limited to solving problems taking into account the core resources separately. Correction of individual resources is carried out sequentially in decreasing order of resource importance and scarcity. The order of schedule correction for certain types of resources depends on the specific situation. Most often in construction practice the limiting resource is labor. The consistent approach leads to the situation in which the identification of the impossibility of resource balance maintenance at any scheduling stage forces to return to the previous steps of iteration [2]. Under the given resource constraints, the rate of convergence of the iterative procedure may not be sufficient for practical implementations or the procedure may even diverge.

2. Speed of project implementation

These and other shortcomings of traditional methods of scheduling of construction process stimulated the search for alternative methods of this problem solving [7]. New prospects for construction scheduling improvement appeared in connection with the introduction of computer technology in the second half of the XXth century and the opportunity to apply methods of operations research (linear and dynamic programming, multicriteria optimization, game theory, etc.) [8]. The use of these methods made it possible to formulate and implement a simple computerized algorithm for describing the project implementation scheduling plan, which became known later as Critical Path Method (CPM) [9]. The development of this approach allowed to create the method of analyzes and assessment of schedules based on the optimization of the process logical scheme (Program (Project) Evaluation and Review Technique - PERT) [10]. Accounting for stochastic external influences, uncertainty and ambiguity of system dynamics is performed by the method of analysis and graphical evaluation (Graphical Evaluation and Review Technique - GERT) [11].

Despite some serious shortcomings inherent in the classical methods of scheduling, they have found the widespread application in world practice. For example, in US, the calendar plan is legally valid and only on its basis relationships between the customer and the contractor are conducted. Thus, the considerable attention is paid to scheduling; it is performed by the individual specialist (scheduler). In the USA scheduling has much more detailed character (than in our national practice) and is based on the widespread introduction of computing technology. [12]. However, the applied over there methods while describing and evaluating schedules do not allow to solve and even set the project optimization problem [13]. In domestic practice, computer technology in solving tasks of scheduling is mostly used in visualization of solutions obtained by empirical methods in the framework of standard software packages [14].

In paper [15] has been shown that the identification of negative trends in the process of project implementation at the early stages of their development is possible not only on the basis of the dynamic analysis of the ratio of planned and actual volumes in physical or price terms, but also in taking into account the planned and real speeds and accelerations of the project jobs (which is the prerequisite for effective and timely correction of project implementation process). Thus, only in this case it is possible to determine the parameters in time and implement a catch-up schedule of jobs, making it possible to minimize the additional project costs and optimize the updated scheduling plan.

The algorithm used in [15] is based on the levelling out the results of dynamic monitoring and on the assumption of a slow change in the averaged speed of the project implementation on the intervals between the monitoring points. This assumption, however, may turn out to be inadequate to the real
situation as long as that the speed of jobs is determined by a small number of nonstockable resources (hereinafter NR). In this case, the discrete nature of resources qualitatively changes both the scheduling process [16] and the course of the project plan implementation. So, for example, if the construction progress (or its stage) is mainly determined by the performance of NR (personnel, machinery, equipment, etc.), then the change between the monitoring points of the number of resources used from $n$ to $n+m$ will lead to the change of project implementation speed in $(n+m)/n=1+m/n$ times. For the close to absolute values of $n$ and $m$, the jump-like change will be quite significant and the assumption of smooth dependence of the velocity on time is incorrect. Consequently, the result of acceleration calculation will be inadequate to reality. The discrete nature of the NR and the associated stepwise use of power makes the definition of speed (as a derivative of work on time) impossible. Let’s define the speed of project implementation at the moment $t_i$ as

\[ V(t_i) = \frac{\Delta F(t_i)}{\Delta t}. \]  

Here $\Delta F(t_i)$ - the increment of jobs performed for the time period $\Delta t$, the value of which (hour, shift, day, week, etc.) is determined by the degree of design detailing and monitoring.

During the levelling out of the monitoring results the initial discrete information will be lost and the forecast of the jobs progress will be impossible. The purpose of this paper is the formulation of the algorithm for dynamic correction of the jobs scheduling performed under the conditions of stochastic influences, taking into account the discrete nature of NR.

The result of the project implementation (with the dominance of discrete resources) is influenced by the two types of stochastic factors. Firstly, by the changes in NR capacity, which is slowly changing during the construction process. For example, throughout the project the personnel qualification, its health condition or the technical condition of equipment may not be in compliance with regulatory requirements. Secondly, the project implementation is influenced by such time-dependent stochastic effects as weather factors, heterogeneity of stored resources, etc. Methods of accounting for these two classes of stochastic factors are different. The influence of these factors slowly varying in time should be dynamically calculated using the monitoring results of construction site and should be taken into account during the forecast update. Moreover, they should be averaged over monitoring intervals.

Figure 1. Speed-time relationship of project implementation for the 210 monitoring points.
Let’s consider the algorithm for determining the time-independent parameters of NR (using a specific example) and forecasting on the base of the results obtained the progress of construction jobs. The dependence of the jobs speed from time can be seen in Figure 1. The graph clearly shows the periods of sharp (much higher than random fluctuations) changes in speed associated with changes in the number of NR resources used. There are also periods (e.g. between monitoring points with numbers lying in the range from 130 to 150) in which the modulation fluctuations are close to the deterministic change in velocity. At the same time, both fluctuations and changes in the capacity of resources have practically no effect on the dependence of the total amount of jobs performed $F(t_i)$ on time

$$F(t_i) = \sum_{j=1}^{V(t_j)} \cdot \Delta t = F(t_{i-1}) + V(t_i) \cdot \Delta t$$  \hspace{1cm} (2)

at the start value $F(t_0) = 0$. Figure 2 shows the dependence $F(t_i)$ throughout the planned time of project implementation. The figure clearly shows the backlog of jobs from the scheduling plan (to the moment of planned project completion) due to the discrepancy between the NR capacities and their passport values.

![Figure 2. Dependence of the fulfilled jobs on time (in % from the total volume of project jobs) with increment $\Delta t$ along the X-axis. On both axes variables take on discrete values, but in real scale the discrete nature of the dependence $F(t_i)$ does not affect the graph form.](image)

The planned capacity of all NRs depends on their distribution in time $N_{\kappa}(t_i)$ and capacity of the separate resource $p_{\kappa}$, where the index defines the types of resources used (e.g. personnel, possessing the relevant competencies; machines or equipment, staffed by personnel, etc.). The assignment of distribution $N_{\kappa}(t_i)$ determines the resource component of the schedule. If the resource of one type (for example, the main equipment) basically determines the course of the project, the distribution $N_{\kappa}(t_i)$ determines the planned project speed $\bar{V}(t_i)$. And this is just the case that will be considered further. The profile of this distribution (corresponding to the construction project considered), is graphically presented in Figure 3.
Figure 3. Plan for the use of nonstockable recourse in the course of project implementation.

Figure 4. Dependence of the schedule fulfillment index on time. Here one can clearly see the constant backlog from the schedule, associated with the decrease in the capacity of NR in comparison with the design values at the initial stage of construction. At the final stage the backlog became more or less stable.

The schedule of work performed $\tilde{F}(t_i)$ is determined by formula (2) with the replacement of the actual speed of work with the planned one: $V(t_i) \rightarrow \tilde{V}(t_i)$

The dependence of schedule fulfillment on time is shown in Figure 4.
As can be seen from ‘Figure 2’ and ‘Figure 4’, the index of jobs fulfillment is much more sensitive to the discrete nature of NR use, than to the amount of jobs performed. The jumps on figure 4 are determined by the change in the amount of resource used and its performance. Monitoring results of the speed of project fulfillment allow to determine the number $j_{\text{max}}$ and full set of points in time at which the change in NR composition occurred. Since at the points $T_j$ the sharp change in the capacity of NR used is taking place, the average acceleration

$$a(t_j) = \frac{\Delta V(t_j)}{\Delta t}, \quad j = 1, 2, \ldots, j_{\text{max}}$$

(3)

takes abnormally large values. This fact is reflected in Figure 5.

Abnormally large values of the average acceleration at the moments of NR composition change are evident. The cut-off zone with the width $2a_{\text{max}}$ corresponds to the speed fluctuations.

![Figure 5. Dependence of the average acceleration $a(t_j)$ of the project implementation on time.](image)

3. Analysis of project implementation

Analysis of the average acceleration on time indicates the presence of uncertainty intervals in which the extrema of average acceleration are present. The formation mechanism of these extrema cannot be clearly established: they can describe both the speed fluctuations and the deterministic processes ‘Figure 5’. Within the framework of the model used, fluctuations cannot be clearly separated from the deterministic processes. However, the separation can be qualitatively performed by introducing the upper limit of the acceleration module $a_{\text{max}}$ for stochastic processes [17]. The result of the contribution of such is shown in Figure 6.

The result of speed averaging in each interval of zero value $\tilde{a}(t_j)$ is shown in ‘Figure 7’.
Figure 6. Dependence of the average acceleration $\bar{a}(t_i)$ determined by the deterministic processes on time with the cut-off parameter $a_{\text{max}} = 0.2$.

Figure 7. Dependence of average speed on time.

A comparison of ‘Figure 1’ and ‘Figure 7’ shows that in the intervals of uncertainty the monitoring performed cannot reliably define the impact of stochastic influences on the process of project implementation. This fact imposes restrictions on the accuracy of forecast of the project completion dates. However, the forecast can be refined by using the alternative method of separating a smooth trend from the stochastic changes, based on the global analysis of empirical array. The principle of separation of the investigated dependencies into deterministic and stochastic parts is based on the decomposition of studied function in a Fourier series [18]


\[ V(t) = \sum_{m=1}^{\infty} b_m \sin(\pi m t) + \sum_{m=0}^{\infty} c_m \cos(\pi m t) \]  

Analysis of the rate decomposition convergence (4) allows to solve the problem of extracting the stochastic information component. This algorithm is based on the qualitatively different behavior of the Fourier decomposition of dynamical and stochastic functions [19]. It allows not only to estimate, but also to isolate the deterministic part of the empirical data. Various modifications of this algorithm are widely used in many areas of science and technology [20]. If there is sufficient empirical information, it allows to select the deterministic part of the information even against the background of stochastic component that coincides with it in order [21]. As a result of using this algorithm, it is possible to fully recover deterministic information and adjust the resource profile on time. The result of the implementation of the catch-up schedule is depicted in Figure 9. The graph clearly shows that the increase in the term of NRs used (without changing their planned volume) allows to finish the construction project in the planned period, even if resources of non-standard capacity are available.

![Figure 8](image-url)  

**Figure 8.** Profile of NR use in the process of catch-up schedule implementation.
Figure 9. The result of catch-up schedule introduction in the first half of the planned period.

Conclusions

Dynamic adjustment of the schedule of construction projects implementation is highly effective in terms of cost and return. Such adjustment should be based on the jobs monitoring in physical or monetary terms. In the presence of external stochastic influences, the averaging of monitoring results over time is necessary. At the same time, only the timely determination of the parameters of catch-up schedule of jobs allows to minimize additional costs and optimize the updated schedule.

If the discrete nature of the resources consumed has little effect on the pace of project jobs, then the parameters of the catch-up schedule are determined by the dynamics of time averaged volumes, rates and accelerations of jobs. In this case, the time dependence of all these parameters is described by smooth functions. In contrast, if the speed of work is determined by the dynamics of nonstockable resources, the speed of work experiences jumps at times of changes in the amount of resources used, which causes a sharp change and derivatives at these points in time. At the same time, the dynamics of the project jobs volume demonstrates weak sensitivity to both the discrete nature of resources and external stochastic influences. In addition, a complete averaging over time leads to the loss of information about these features of construction dynamics.

The project implementation rate is influenced by two types of stochastic factors, which leads respectively to the quick and slow change in construction speed. The influence of factors rapidly changing in time should be averaged over monitoring intervals. In contrast, the contribution of slowly changing factors should be updated according to the results of construction process monitoring and should be taken into account in forecast creation. Due to these features, the algorithm for formation of the catch-up schedule of jobs cannot be based on the full averaging of monitoring results over time, not on the analyzing the volumes and accelerating the project process. The proposed in this paper algorithm is based on the results of monitoring the jobs pace and averaging them only over the periods of constant composition of discrete resources number.

External stochastic effects lead to the emergence of periods of sharp jobs pace changes (associated with changes in the amount of resources used), as well as to the periods in which the modules of fluctuations have the same order as the deterministic speeds change. The method of separation of stochastic and deterministic effects is based on the analysis of average (for the time between monitoring points) accelerations. The algorithm of extracting of the deterministic component can be based both on the empirical rule of the cut-off zone and on the qualitative difference in the Fourier spectrum of stochastic and deterministic functions. In the first approach the part of the original
information is lost. The Fourier analysis of monitoring results allows to fully restore all the deterministic information even against the background of stochastic signal that coincides with it. In any case, the proposed algorithm allows us to formulate the parameters of the catch-up schedule of jobs, which allows to avoid some financial and image losses associated with the late completion of the project or its main parts.

References
[1] Dikman L G 2006 Organization of construction production (Moscow: ASV) [In Russ]
[2] Levy Sidney M 2007 Project management in construction (New York-Chicago –San Francisco: McGraw-Hill)
[3] Vasilev V M 2001 Management in construction (Moscow: ASV) [In Russ]
[4] Kievs'kyi L V 1987 Complexity and flow (Moscow: Stroizdat) [In Russ]
[5] Afanasiev A V 1982 Improving the organization and management in construction (Leningrad: LECI) pp 13–22 [In Russ]
[6] Gusakov A A 1994 Organizational and technological reliability (Moscow: SVR-Argus) [In Russ]
[7] Larichev O and Sternin M 1992 Knowledge-based approach for solving the multicriteria assignment problem (Models of problem solving. Arbeitspapiere der GMD 630 Sisyphus) ed Linster M
[8] Uskov V V 2016 Innovations in construction: organization and management (Moscow: Infra-Ingeneriya) [In Russ]
[9] Krüger, Wilfried 2006 Excellence in Change - Wege zur strategischen Erneuerung, 3 Auflage, (Wiesbaden: Gabler Verlag) pp 212-213
[10] Project Management Institute 2013 A Guide to the Project Management Body of Knowledge (5th ed.) (Project Management Institute)
[11] MacCrimmon K R Ryavec Ç A 1964 An Analytical Study of the PERT Assumption (Opt. Res. vol 12 No 1) pp 16–38
[12] Dikman L G, Dikman D L 2004 Organization of construction in America (Moskow: ASV) [In Russ]
[13] Larichev O I, Pavlova L I and Osipova E A 1990 Problems and methods of making unique and repetitive decisions Sbornik trudov № 10 (Moscow: Institut Sistemnogo Analiza) pp 66–74 [In Russ]
[14] Uskov V V 2011 Computer technologies in the preparation and management of construction projects (Vologda: Infra-Ingeneriya) [In Russ]
[15] Mishchenko V YA, Dobrosotskikh M G, Elena El Earthbourne 2019 Optimization of the Construction Operation Scheduling Through Redeployment of Nonstockable Resources. Nedvizhimost: ekonomika. Upravleniye vol.1 pp 83-87
[16] Mishchenko V YA, Dobrosotskikh M G 2016 NP Solvable task of scheduling of construction, reconstruction and repair of objects Proceedings of higher educational institutions. Textile industry technology vol. 6 (366) (Ivanovo: IVSPU) pp 13-20
[17] Smith L P 2003 Mathematical Methods for Scientists and Engineers (NewYork: Prentice Hall Inc. Englewood Cliff)
[18] Anders V 2003 Fourier Analysis and Its Applications. Series: Graduate Texts in Mathematics vol 223 (New York: Springer-Verlag) p 272
[19] Schoenberg I J 1998 Some Analytical Aspects of the Problem of Smoothing, Courant Anniversary Volute (New York: Interscience Publishers)
[20] Preobrazhenskii M, Rudakov O, Popova M and Tran Hai Dang 2017 Journal of Science and Technology Natural science – engineering – technology vol 169 №9 pp 89-92
[21] Pierre Brémaud 2014 Fourier Analysis and Stochastic Processes (Springer International Publishing AG)