Mechanisms of Increase in Organizational and Technology Reliability at Management of Innovative Construction Production

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Abstract. In article the problem of distribution of technology dependent works on contractors is considered during creation of the innovation production due to capital investments in means of mechanization and automation of construction production that allows to construct such schedule by means of which time of accomplishment of the corresponding amount of works is minimized by the set great number of contractors and the optimum sequence of their accomplishment is defined. At the same time job sharing on contractors with use of methods of research of stream — Dijkstra's algorithms is considered optimum. The relevance of creation of this model is defined by need of rational use of human resources. It is possible to carry possibility of process description of construction to advantages of model at the same time of several objects the innovation means of production with increase in parameters of organizational and technology reliability.

1. Introduction

Various network models are used for the description of construction processes and calculation of schedules at investment in format of the capital investments. The theory of their structure developed in the direction of refining of methods of calculation of predictions of works, the best accounting of the relations between them [1,2] and influences of external factors [3]. The deconstruction of their structures is that they cannot be used. If tasks are interpreted as the technology transactions which are carried out by construction machines on all construction objects making series, the task consists in creating the schedule for accomplishment of this series on the basis of the project of investments in the form of capital investments. The calendar more general concerning the known problems of the theory of time which explain the situations connected with production planning. Prerequisites for large number of works is the procedure in which not only concrete subjects, but also tasks of the theory of programs [4,5], but also production of all elements providing production are limited. Such tasks often
arise during creation of the innovation construction productions, such as volume and block housing construction, use on building sites of mechanisms of intensification of works that significantly influences parameters of increase in organizational and technology reliability.

2. Problem definition

The model of scheduling of process of distribution of technology dependent works on contractors allows to solve problem of creation of such schedule by means of which time of accomplishment of the corresponding amount of works is minimized by some great number of contractors and the optimum sequence of their accomplishment is defined.

The model of optimum job sharing on contractors is under construction with use of methods of research of stream — Dijkstra's algorithms and defect [6]. For realization of this model on the computer it is necessary to have information not only on standards and terms of performance of works, but also on the qualitative level of contractors, that is to have assessment of their qualification, specialization, experience and individual opportunities.

The relevance of creation of this model is defined by need of rational use of human resources. It is possible to carry possibility of process description of construction to advantages of model at the same time of several objects [7].

Below the technology dependence only of one type (fig. 1) is considered:

\[ T_i^n \geq T_j^k \]

where: \( T_i^n \) — time of the beginning of performance of work \( i \);

\( T_j^k \) — time of the end of performance of work \( j \).

According to this dependence work of \( i \) is considered technology dependent on work of \( j \) if its accomplishment can be begun only after the end of performance of work of \( i \). Some object with the corresponding set of works is Let's say projected. On the basis of expert evaluations of the sequence of performance of works we will enter network \( G \) in which knots (elements) are works, and arches define dependence of hub \( i \) on \( j \).

We will call this network regular if in it there are no contours [8,9]. The contour is understood as certain sequence of works: \( i_0, i_1, ..., i_n, i_0 \). If at network \( G \) there are contours, then for their destruction it is enough to withdraw one of the arches making it from each of them. For this purpose on the basis of results of additional expert research we will define the technology dependence (arch) having the small probability of realization and specified for this reason by the expert as not essential.
3. Algorithm of optimization of durations of accomplishment of each work

At determination of the sequence of performance of works and their durations for average time \( \tau_i \) of performance of work of \( i \) we find change ranges: \( [\tau_i^+, \tau_i^-] \) [3]. We consider technology communication of works only within the specified dependence. If such dependence is not carried out, then it is necessary to break work into sites so that for all set of works and sites the dependence was carried out.

Best value \( \tau_i \in [\tau_i^+, \tau_i^-] \) let's calculate by means of criterion of the maximum yield gained as a result of end of all amount of works. For the solution of objective, we use algorithm of optimization of durations of accomplishment of each work [10]. Let's consider the focused network without contours. We will call sources all elements of the focused network which arches only leave, and elements which arches only enter - drains. Let's enter fictitious element which is combinable with all sources therefore we will receive one main source and several drains. For accomplishment of the iterative procedure of leveling of difference in \( \{\text{length}\} \) between the shortest and the longest (critical) the chains connecting the main source of \( S \) with \( t \) drain we will use Dijkstra's algorithm [11]. For this purpose we will enter the generalized cost of the works performed by the time of the beginning of work \( i_1 \), — \( C_{i_1, i_2} \).

\[
C_{i_1, i_2} = \begin{cases} 
0, & \text{if } i_2 \in S, \ i_1 \in \tau_i; \\
\infty, & \text{if arches } (i_1, i_2) \text{ in network does not exist}; \\
\tau_1(d_{i_1} + U_{i_2}), & \text{for all other arches of network}; 
\end{cases} \tag{2}
\]

where: \( d_i \) — income from performance of work \( i_i \); 
\( U_{i_2} \) — total income from accomplishment of all works depending on work \( i_i \).

The size of the amount \( (d_{i_1} + U_{i_2}) \) of income is set and is defined together with the customer.

The chain of the knots of network \( G \) which are consistently connected by arches connecting the main source of \( S \) with any of drains is called final chain [12].

The final chain is called the shortest if for it value of function:

\[
W_\xi = \sum_{k=1}^{m+1} C_{i_{k-1}, i_k}, \ i_0 = S, \ i_{m+1} = t_\xi \tag{3}
\]

will be minimum, and critical (longest) if the value of this function is maximum.

For each element \( i \ (i = 1, N) \) networks \( G \) total income of \( U_i \) for final element (drain) \( \xi \), is equal to revenue of \( d_\xi \) which it will yield after accomplishment of work \( i \).

Then:

\[
U_{i_1} = \sum_{i_2} U_{i_1, i_2} + d_{i_1}, \ U_{i_1, i_2} > 0, \tag{4}
\]

where: \( U_{i_1, i_2} \) — income size \( U_{i_2} \) for \( i_2 \) element which is directly preceding element \( i \).

Using algorithm of the solution of task on the shortest chain at:

\[
C_{i_1, i_2} = \tau_1(d_{i_1} + U_{i_2}),
\]

\[
C_{i_1, i_2} = \tau_1(d_{i_1} + U_{i_2}), \tag{5}
\]

find respectively the shortest and longest chains from the main source of \( S \) to \( t_\xi \) for each final element \( \xi \). Also the difference of lengths between the longest and shortest chains is calculated:

\[
\Delta_\xi = \sum_{k=1}^{n+1} \tau_{i_{k-1}}(d_{i_{k-1}} + U_{i_k}) - \sum_{k=1}^{m+1} \tau_{i_{k-1}}(d_{i_{k-1}} + U_{i_k}) \tag{6}
\]

where: \( \xi \) elements \((n+1)\) and \((m+1)\) — final element \( t_\xi \),

zero — the main source \( S \).
For each \( i_k \) - that element of the longest chain and the \( i_t \) element of the shortest chain respectively are defined their weight (share of the generalized cost of works by the time of performance of work of \( i_k \)).

\[
P_{i_k} = \frac{C_{i_k,i_{k+1}}}{\sum_{k=0}^{m}(C_{i_k,i_{k+1}})}
\]

(7)

\[
g_{i_k} = \frac{1}{C_{i_k,i_{k+1}} \sum_{k=0}^{m}(1/C_{i_k,i_{k+1}})}
\]

For each final element \( \xi \) the longest and shortest chains we find sizes \( \delta_{i_k}^{\pm} \) and \( \delta_{i_t}^{\pm} \) by which in the absence of restrictions it is necessary to reduce and increase respectively duration of performance of works \( i_k \) and \( i_t \):

\[
\delta_{i_k}^{\pm} = 0.5\Delta_{\xi_k}^{\pm} P_{i_k}, \quad \delta_{i_t}^{\pm} = 0.5\Delta_{\xi_t}^{\pm} P_{i_t},
\]

(8)

The value \( \xi \) of the shortest final chain \( \tau_i^{\ominus} \) increases by size:

\[
\Delta \tau_i^{\ominus} = \min \{ \min \{ \delta_{i_k}^{\pm}, \xi = 1, N_f \} \tau_{i_k} - \tau_{i_k} \}
\]

(9)

and the value \( \xi \) of the longest final chain \( \tau_i^{\oplus} \) decreases by size:

\[
\Delta \tau_i^{\oplus} = \min \{ \min \{ \delta_{i_t}^{\pm}, \xi = 1, N_f \} \tau_{i_t} - \tau_{i_t} \}
\]

(10)

where: \( N_f \) — quantity of final elements.

It should be noted that (9) and (10) networks are built for each \( i \)-that element and also the fact that at increase \( \tau \) at element \( i \) of the shortest chain the condition has to be satisfied always \( \Delta \xi \geq 0 \).

Correction of values \( \Delta \tau_i^{\ominus} \) and \( \Delta \tau_i^{\oplus} \), for all elements of final chains \( \xi \) (\( \xi = 1, N_f \)) is carried out on formula:

\[
\tau_i^{[1]} = \tau_i^{\ominus} + \Delta \tau_i^{\ominus},
\]

\[
\tau_i^{[1]} = \tau_i^{\oplus} + \Delta \tau_i^{\oplus},
\]

(11)

The subsequent [13] iterations are carried out as well as the first, with only that difference that in them their values corrected on the previous iteration on formulas undertake original values of durations \( \tau \) performance of works of \( i \) (11).

Iterative process continues until values \( \Delta \xi \), \( \xi = 1, N_f \) decrease not less than by size \( \varepsilon \) (\( \varepsilon \approx 5\% \) for \( \Delta \xi \) on the previous step). As a result of iterative process best values of durations of accomplishment of each work are defined.

Let's consider the set great number of contractors of \( M \) for whom standards of duration of accomplishment by each contractor of \( j \) of work of \( i \) are known, that is it is busy during \( T_j \) time. Let's enter determinations of level of network [14].

We call set of knots of network \( G \) technology dependent if between knots the dependence is carried out (1).

The set of knots of network \( G \) is called zero level \( G_0 \) if knots of this set are technology independent.

We call set of knots of network \( G \) the \( n G_n \) level if it meets the following conditions:
- the set of these knots can be technology dependent on set knots \( G \), where \( N \) - number of levels in network \( G \);

- set of these knots technology irrespective of set knots \( \bigcup_{i=n}^{N} G_i \).

From the given definitions the following investigations follow [15]:

1. If the number of levels is equal to one \( (N = 1) \), then the set of hubs \( G \) is technology independent and is set of the elements which are not connected among themselves.

2. If among elements of set of \( G \) there is at least one technology dependence of the specified type, then the set of \( G \) is called network and has, at least, two levels.

3. If the set of \( G \) is network, then equality is fair \( G = \bigcup_{i=0}^{N} G_i \), where \( N \) — number of levels.

The example of creation of levels in network \( G \) on the basis of their offered determination is shown in fig. 2.

Network \( G \) contains five levels.

Let’s consider all elements sources (works) of the first \( N_1 \) level of network \( G \). Let’s assume that for any level of network \( G \) the condition of \( M > N \), where, \( n \) is number of levels in network \( G \) is fair, i.e. for each level the number of contractors are not less number of knots of this level [16]. Then the set of works of the first \( N_1 \) level owing to their technology independence can be distributed between great number of contractors by method of the solution of task on appointments by criterion:

\[
\sum_{i=1}^{N_1} \sum_{j=1}^{M} \left( t_{ij}^{(0)} + \Delta T_{ij} \right) X_{ij} \rightarrow \text{min},
\]

where: \( \Delta T_{ij} \) - standard interval of time of performance of work of \( i \) by the contractor \( j \);

\( M \) - number of contractors;

\[
X_{ij} = \begin{cases} 
1, & \text{if work of } i \text{ is performed by the performer of } j \\
0, & \text{otherwise}
\end{cases}
\]
4. Distribution of set of technology dependent works on contractors

As a result of the solution of task on appointments we will get distribution sets of technology independent job on contractors (fig. 3).

At the same time we will receive also new loading of contractors which we will define as follows:

\[ T_j^{[1]} = \begin{cases} T_j^{[0]} + \Delta T_{ij}, & \text{if the contractor of } j \text{ performs work of } i \\ T_j^{[0]}, & \text{otherwise} \end{cases} \]

Let's pass to job sharing of the second level on contractors now, applying method of the solution of task on appointments by criterion (12) with new loading of contractors on formula (13). This process of job sharing on contractors comes to an end on job sharing of the last \( N_n \) level. The corresponding distribution of set of works of \( N \) on contractors will be as a result found (fig. 4).

For determination of the general deviation [17, 18] of the received timepoints of the beginning and completion of works from their best values we will use formulas (fig. 5):

\[ I^{[1]} = \sum_{j=1}^{M} \sum_{i=1}^{N} \left( \Delta T_{ij}^{n^2} + \Delta T_{ij}^{k^2} \right) \]

\[ \Delta T_{ij}^{n} = T_{ij}^{n} - T_{ij}^{n} ; \]

\[ \Delta T_{ij}^{k} = T_{ij}^{k} - T_{ij}^{k} , \]

where: \( T_{ij}^{n} \) - timepoint to which the contractor of \( j \) will be free from works, that is duration of loading of the contractor of \( j \).
Let's consider deviation of terms of accomplishment of some \( j \) of work of \( i \) distributed on the contractor from their best values. If for work of \( i \) the condition is complied:

\[
\Delta T^n_{ij}^2 + \Delta T^k_{ij}^2 = 0, \tag{14}
\]

that this work is performed in optimum terms.

If the condition (15) is not satisfied, then time of performance of work of \( i \) deviates optimum term at size \( |\Delta T^n_{ij}| + |\Delta T^k_{ij}| \).

For repeated distribution of technology dependent works on contractors we will correct planned dates of their accomplishment as follows:

\[
T^k_i = \begin{cases} 
T^n_i & \text{if } T^n_i - T^k_{ij} \geq 0 \\
T^k_{ij} & \text{if } T^n_i - T^k_{ij} < 0
\end{cases} \tag{15}
\]

As a result of correction of deadlines of performance of works we will pass to new job sharing of each level on contractors and on this basis we will determine the general deviation of the received new timepoints of the beginning and the termination from their best values (fig. 5) by formulas (15).

**Figure 4.** Distribution of set of technology dependent works on contractors.

**Figure 5.** Determination of deviation of time of the beginning and completion of works from their best values at \( T^n_i > T^n_{ij} \) (a) and \( T^n_i < T^n_{ij} \) (b).
If inequality is fair:

\[ f^{k+1}_i, f^k > 0 \]

that new distribution will be better, than previous.

If inequality (17) is not carried out, then the received distribution is worse previous. In this case correction of deadlines of accomplishment of all amount of works is also made, and serial job sharing on contractors is performed again. Iterative process of approach to optimal solution comes to an end; if it is impossible to improve this decision more.

Let's consider case when the number of contractors \( M \) is less than number of works at least at one level, for example on level \( N_n \), t.e. \( N_n > M \). Then the procedure of job sharing for contractors will be several another. Let's consider works of level \( n \), in which \( N_n > M \). Let's choose the \( M \) works from \( N \) so that the following inequality was carried out:

\[ \max T^n_i < \min T^n_i, i = 1,M, i = M + 1,N_n \]

If initial timepoints coincide at least at two works, then it is necessary to include in set of the distributed works such which has termination moment the smallest of two works, that is:

\[ T^n_i \leq T^n_j \]

5. Conclusion

The certain number of works equal to \( M \), we distribute as well as at \( M \geq N_n \). If the remained set of works \( N_n > M \), that on the basis of (18) and (19) we repeat allocation of set of works of \( M \) and we make their same distribution, as at \( M > N_n \). We continue to perform these procedures until the condition according to which the number of the remained works are less than number of contractors is satisfied.

Thus, we will get distribution sets of job of level \( N_n \). If at the following \( N_{n+1} \), level the number of works exceeds number of contractors of \( M \), we will apply the distribution made at the level \( n \). Otherwise distribution is made as at \( N_{n+1} \leq M \). The offered method of the solution of problem of distribution of technology dependent works on contractors allows to carry out their distribution taking into account increase in parameters of organizational and technology reliability of installation and construction works taking into account introduction of the innovation automation equipment and mechanization.

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