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DANIEL PRZYWARA, ADAM RAK*

TIME AND COSTS ANALYSIS OF PRODUCTION LOSS IN BONDED TECHNOLOGICAL WORKS SERIES

ANALIZA CZASOWO-KOSZTOWA STRAT PRODUKCYJNYCH W WIĄZANYM CIĄGU TECHNOLOGICZNYM ROBÓT

A b s t r a c t

Production downtime results from the technological regime of production processes, established in production diagrams as network nodes. Their direct cause in the lack of harmonization between working teams, diversity of performance of hardware units – working in mixed systems, and different labor construction processes, performed on the same working plots. Time and costs analysis lies in optimizing the downtime of production resources using the "by-pass" production, which allows production labor (*R*) and hardware measures (S) for the implementation of part of the process. This tool is defined in network nodes, slowing down the production and binding the run of the production front with a two criteria network plan: technologically and organizationally. The technique is based on an algorithm of the limitations of renewable resources of means of production, which assumes the full availability of construction materials, available from storage sites. The paper presents an analysis of fixed and variable investments costs in terms of compensating for downtime.

Keywords: monitoring costs, schedule, production loss, by-pass

S t r e s z c z e n i e

Przestoje produkcyjne wynikają z reżimu technologicznego procesów produkcyjnych, utrwalonych w diagramach produkcyjnych w postaci węzłów sieciowych. Ich bezpośrednią przyczyną jest brak harmonizacji w pracy brygad roboczych, zróżnicowanie wydajności jednostek sprzętowych – pracujących w mieszanych układach – oraz odmienne pracochłonności procesów budowlanych, wykonywanych na tych samych działkach roboczych. Próba analizy czasowo-kosztowej polega na optymalizacji przestojów środków produkcji przy zastosowaniu *by-passu* produkcyjnego, który zezwala robociźnie produkcyjnej (*R*) i środkom sprzętowym (*S*) na realizację części procesu. Narzędzie definiowane jest w węzłach sieciowych, wyhamowujących produkcję, wiążących bieg frontu produkcyjnego przez plan sieciowy dwukryterialnie: technologicznie i organizacyjnie. Technika bazuje na algorytmie ograniczoności odnawialnych zasobów środków produkcji. Zakłada pełną dostępność surowców i materiałów budowlanych, dostępnych z placów składowych. W pracy przedstawiono analizę kosztów stałych i zmiennych inwestycji, pod kątem podatności na wyrównanie przestojów.

Słowa kluczowe: monitoring kosztów, harmonogram, straty produkcji, by-pass

* M.Sc. Daniel Przywara, Prof. D.Sc. Ph.D. Adam Rak, Departament of Buildings Systems Engineering, Faculty of Civil Engineering, Opole University of Technology.

1. Introduction

Costs control during implementation helps to maintain the required number of intervals, as well as material and temporal parameters of the investment [4]. The main object of control is the investment budget, revised at certain intervals (e.g. monthly) or continuously.

Problems associated with uniform working methods were initiated in the USA, where the case of repeatable project planning methods where based on the equilibrium line method, described as LOB (*Line of Balance*), LSM (*Linear Scheduling Method*), VPM (*Vertical Production Method*) [3].

A uniform work order on the working fronts by a site foreman provides a sense of organizational control. However, if fronts working differ due to an assortment scope of work, then such a system can be unfavorable for harmonization. It is not difficult to imagine a situation in which one working front is waiting for the release of the next (in the current schedule), although the team could continue on an other working front, the team (Known as a brigade) may be planned for a different task following on from the one they are working on [8].

Here a tool named the production "by-pass" may be useful as it can help to minimize downtime by allowing for renewable production resources (*R* and *S*) in order to proceed with selected working operations [11].

In the control of construction processes, operating within production systems, the philosophy of control [2], which is the permanent supervision and analysis of activities from the point of view of the objectives, and possibly the earliest introduction of control measures. Production losses, resulting from downtime are an inherent and undesirable element of any investment cycle.

They may be caused by random chance, due to the impact of external factors (weather, punctuality of suppliers and subcontractors etc.) which do not depend directly on the contractor.

These restrictions cannot be controlled in the preparation of the overall construction schedule. This can be done at the end (*ex post*) of consecutive stages of production, by analyzing whether there are retained [7].

Technological and organizational factors, involving the lack of adequate monitoring processes and response to the increasing deviation of the planned costs to those actually incurred also play a part.

An adopted costs plan, used as reference for the monitoring and control of costs throughout the duration of the investment cycle is shown in [12].

Modeling of works technology, the construction of models describing the structure and parameters of the technical, technological, organizational and economic resources means distinction and description of resources, dictating the analyzed processes timing and construction costs are shown in [6].

Coupling successive working fronts bind subsequent works of all kinds, inside each partial complex, specifying the degree of continuity of occupation of partial fronts [9]. If, on the front after the preceding job immediately begins the next one (there are no down times at the front), coupling is equal zero. Relations between fronts then shorten the total time of works execution.

Coupling occurring between working parcels, which are elements of the examined system [5], may constitute a direct relationship between successive bands of related processes or effect the activity within technological process, supported by common renewable resources.

In any case they will create cost-intensive down times – caused by variable labor-intensive processes on the plots and different founds circulation.

2. Subject matter and methodology of research

The subject of this research is the search for wasted production times, irretrievably lost in the organizational division on the verge of separation: *i* process/*j* plot ($I = l, \ldots, m; j = l, \ldots, n$) – by the limitations of the schedule.

Test methods based on predetermined objective functions define a time (workload) and costs (financial effort) of the analyzed process and the relocation of production means from its predecessors (i–1) to the successors (i+1) of the examined *i* process and to the numerically corresponding working plots.

3. The results of time and costs analysis

3.1. The matrix of the bound technological sequence

The choice of technological sequence schedule is determined by the links between labor and equipment as well as between successive building processes (i), supported by the same means of production.

Production in the range of reinforced concrete monolithic constructions binds ranges of reinforcement works and carpentry-concrete works. Constructing concrete sleepers for foundations (with staking) is made by carpenters and concrete workers (A) – for the next step these teams perform the so called opening and routing of form work for the sleepers is carried out.

Teams of steel fixers (B) arrange and bind grid/reinforcement baskets with spacers; followed by the installation of starters – reinforcement grids for fixing column and wall foundations. Carpenters (A) then close and fill concrete into these foundations: by this time at a square near the facility cutting and bending reinforcing steel for walls and columns is taking place (brigade B). After the removal of the form work by foundation teams from (A) walls and columns – after the installation of reinforcements (B) closure and concreting the components (A). Relationships that exist between these processes, takes the degree of division of an object on working plots and their workload, expressed with time and realization costs into account.

When analyzing the time-cost m of construction processes, implemented on n working plots through two ranges of renewable resources (A, B), the matrix of the bound technological sequence is:

$$C_{ij} = \begin{bmatrix} c_{11}^{A} & c_{12}^{A} & \ldots & c_{1j}^{A} & \ldots & c_{1n}^{A} \\ c_{21}^{B} & c_{22}^{B} & \ldots & c_{2j}^{B} & \ldots & c_{2n}^{B} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ c_{i1}^{A} & c_{i2}^{A} & \ldots & c_{ij}^{A} & \ldots & c_{in}^{A} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ c_{m1}^{B} & c_{m2}^{B} & \ldots & c_{mj}^{B} & \ldots & c_{mn}^{B} \end{bmatrix}_{mxn} \tag{1}$$

where:

$c_{ij}^{A/B}$ – generalized matrix component, which expresses the time of production measures (*A/B*), performing the *i* construction process (*I* = 1, …, *m*) on *j* working plot (*j* = 1, …, *n*) of the construction [r–g/m–g].

3.2. The definition of the objective function

The purpose of the issue consists of minimizing downtime in production labor (R) and equipment (S) is used to define interruptions at work (T_{ij}), resulting from the need to maintain the technological regime and organizational disruptions, while transferring the means of production on these front works (*i–j*) which is the continuation of production.

If a x_{ij} (*I* = 1, 2, …, *m*; *j* = 1, 2, …, *n*) will be marked with a decision variable, defining a change of allocation of means of production of the *j* working plot and the *i* process for the future process *i+p* (*p* = 1, …, *m*–1), carried out on any successor plot *j+q* (*q* = 1, …, *n*–1) and by the k_{ij} corresponding to time production costs, the above problem of reclassification of renewable resources can be expressed as a function of the production purpose, minimizing production downtime:

$$\min(z) = \sum_{i=1}^{m}\sum_{j=1}^{n} k_{ij} \cdot x_{ij} \tag{2}$$

where:

k_{ij} – production cost in relation to process *i* on *j* working plot,

x_{ij} – decision variable (binary), making the reclassification of means of production, this problem has the following constrains:

1)
$$x_{ij} = \begin{cases} 1 \\ or \\ 0 \end{cases} \tag{3}$$

2)
$$k'_{ij} \le \sum_{i=1}^{m}\sum_{j=1}^{n} k_{ij} \cdot x_{ij} \tag{4}$$

3)
$$p:(i, i+1), \quad q:(j, j+1) \tag{5}$$

4)
$$x_{ij} \neq 0 \rightarrow y(T)_{i+p,j+q}^{A,\ldots,B} : \sum_{p=1}^{m-1}\sum_{q=1}^{n-1} c_{i+p,j+q} \tag{6}$$

where:

k'_{ij} – production costs (*Ks+Kz*), reduced relative to baseline,

p, *q* – measures of the displacements of means of production within rows (processes) and columns (working plots) within the matrix of the bound technological sequence,

$y_{i+p,j+q}^{A,\ldots,B}$ – vector expressing displacement (*p*, *q*) means of production (*A* or *B*) – numerically about the process (*i+p*) and about the working plot (*j+q*).

The constrains of the objective function is the binary nature of the decision variable (3).

The resulting value of production costs of production processes (4) can't be higher than the planned costs – after the application of the algorithm. Measures of displacement of production means (5) define the displacements vector (y) held in the working direction of the successor of the analyzed process: they cannot be retroactive – as a result of the technological regime of works. Nonzero value of the decision variable (6) assigns the vector moving the means of production to the first construction process, on which the continuation of a construction working plot is possible during the term of its predecessor.

3.3. Time-cost matrix with movements of means of production

The adopted model of tasks allows for a flexible approach to the schedule optimization problem, by controlling the allocation of renewable resources.

The recognition of time and costs analysis comes down to assigning values to the planned production costs of construction processes schedule, taking their price setting components (R, M, S) and markups on the costs into account(Kp, Kz, Z).

After extracting those values from the offer cost estimate the matrix takes the form:

$$C(k)_{ij} = \begin{bmatrix} c(k)_{11}^{A} & c(k)_{12}^{A} & \dots & c(k)_{1j}^{A} & \dots & c(k)_{1n}^{A} \\ c(k)_{21}^{B} & c(k)_{22}^{B} & \dots & c(k)_{2j}^{B} & \dots & c(k)_{2n}^{B} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ c(k)_{i1}^{A} & c(k)_{i2}^{A} & \dots & c(k)_{ij}^{A} & \dots & c(k)_{in}^{A} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ c(k)_{m1}^{B} & c(k)_{m2}^{B} & \dots & c(k)_{mj}^{B} & \dots & c(k)_{mn}^{B} \end{bmatrix}_{m \times n} \tag{7}$$

where:

$c_{ij}(k)^{A/B}$ – generalized matrix component, which expresses the time of production (A/B), and the corresponding production costs (k) ($I = 1, \dots, m; j = 1, \dots, n$).

4. Usage in engineering

In order to illustrate the assumptions above, time-cost analysis were adopted as a temporary coupling of two work fronts, on which carpentry and reinforcement works are carried out. The technological sequence refers to the process of implementation of a monolithic slab made of reinforced concrete above the ground floor of the museum building, resting on monolithic reinforced concrete columns.

In the process presented, eight working operations were isolated (rows of the matrix) performed on four plots (columns).The values of the duration of operations were recorded in service hours (r–g). due to the costs (k), describing the fix and variable costs, the components are stored in the value of 1/1000 (PLN). The time-cost matrix, isolated from the general construction schedule (*c*) and offer cost estimate (*k*) takes the form:

$$C(k)_{ij} = \begin{bmatrix} 6(0,5)^A & 6(0,5)^A & 6(0,5)^A & 6(0,5)^A \\ 2(0,3)^B & 2(0,3)^B & 2(0,3)^B & 2(0,3)^B \\ 1(0,5)^A & 1(0,5)^A & 1(0,5)^A & 1(0,5)^A \\ 8(0,9)^A & 6(0,7)^A & 5(0,6)^A & 8(0,9)^A \\ 4(2,7)^B & 3(2,5)^B & 2(2,2)^B & 4(2,7)^B \\ 1(0,3)^A & 1(0,3)^A & 1(0,3)^A & 1(0,3)^A \\ 1(3,5)^A & 1(3,2)^A & 1(3,1)^A & 1(3,6)^A \\ 2(0,3)^B & 2(0,3)^B & 2(0,3)^B & 2(0,3)^B \end{bmatrix}_{8\times 4} \tag{8}$$

Working on plots, teams of carpenters (*A*) construct formwork for columns (line 1), concrete columns (line 3), the floor slab formwork (line 4), stamping of the floor (line 6) and its filling with concrete (line 7).

Teams of steel fixers work on the reinforcements of columns (line 2) and the reinforcement of the floor stab (line 5). For the analysis of one working plot (e.g. column number 1 of the matrix), with the method of future embodiment, the total duration of the process on the plot is: 6 + 2 + 1 + 8 + 4 + 1 + 1 + 2 = 25 r–g, with the total production cost (*Ks*+*Kz*) at 8700 PLN.

Differences in the cost of production on the plots, with identical labor needs, are due to the participation of material costs of the operation: lack of material component while stamping the floor (line 6) is characterized by costs several times lower in relation to concreting of the floor stab (line 7) – at the same time value.

The role of the “by-pass” is to streamline the production downtimes, generated when changing the assortment of means of production (labor), serving the analyzed construction process. These downtimes are formed in the matrix of bound technological sequence between the lines 1 – 2, 2 – 3, 4 – 5, 5 – 6, 7 – 8 – which is where one working team (brigade) – alternating between *A/B* – must make the working front available for the second team.

Waiting time – in the classical sense of the schedule – is lost time. The “by-pass” tool allows for both means of production realization as well as progression of some of the working activities during waiting time – while retaining the technological regime – in the course of their standstill, which – from a cost point of view – which is sometimes lost irrevocably.

The process of improved continuity is shown by the time-cost matrix (9). After the concrete column reinforcement baskets are completed (line 2), steel fixers (*B*) working on reinforcement of the floor stab (line 5) – the analysis of plot 1 – occurs after 9 r–g (sum of lines 3+4). At this time, minimizing the time buffer, created by waiting for the continuation of the process, team (brigade (*B*) proceeds with the pre fabrications of reinforcement of the stab: cutting and bending of steel, stirrup ruff ribs, (according to expenditures: 50% of labor need).

$$C(k)_{ij} = \begin{bmatrix} 6(0,5)^A & 6(0,5)^A & 6(0,5)^A & 6(0,5)^A \\ 2(0,3)^B & 2(0,3)^B & 2(0,3)^B & 2(0,3)^B \\ 1(0,5)^A & 1(0,5)^A & 1(0,5)^A & 1(0,5)^A \\ 8(0,9)^A & 6(0,7)^A & 5(0,6)^A & 8(0,9)^A \\ \overline{2}(\overline{1,4})^B & \overline{1,5}(\overline{1,3})^B & \overline{1}(\overline{1,1})^B & \overline{2}(\overline{1,4})^B \\ \overline{0}(\overline{0,0})^A & \overline{0}(\overline{0,0})^A & \overline{0}(\overline{0,0})^A & \overline{0}(\overline{0,0})^A \\ 1(3,5)^A & 1(3,2)^A & 1(3,1)^A & 1(3,6)^A \\ \overline{0,5}(\overline{0,1})^B & \overline{0,5}(\overline{0,1})^B & \overline{0,5}(\overline{0,3})^B & \overline{0,5}(\overline{0,1})^B \end{bmatrix}_{8\times 4} \tag{9}$$

Management of production downtime – which in part resulting from the technological regime – will reduce, in a measurable way, the duration of line 5 of the matrix by half.

Similarly in case of team (brigade) changes (from *A* to *B*) in lines 5–6 of the matrix work sequence. Stamping of ceiling formwork is an operation which does not require the expectations of means of production at the end of the reinforcement of reinforced concrete elements. And here the "by-pass" prevents the downtime of teams (brigades) (*A*), eliminating downtime completely and allowing the carpenters to continue working.

The duration of the operation in line 6 is therefore zero, fits entirely into the time duration of its predecessor – the operation in line 5. Hence the costs of these activities, also paid for while at a standstill – regarding the renewable *B* resources (*R* and *S*) – are zero.

The standstill of steel fixers (line 5–8) will be used on another prefabricationof reinforcement for separate concrete structures: columns and sub strings of the first floor.

The installation of finished baskets and figures in accordance with factual inputs (*R*, *M*, *S*) requires 25% of time and 33% of costs of production of the starting expenditures: assuming that those activities will be carried out using the "by-pass" technique, while awaiting measures which will make the work front available again.

5. Conclusions

The analysis of time and costs of production downtime in the matrix of the bound technological sequence, using a production "by-pass" shows profits.

The variable costs of the process (*Kz*), with a constant composition of the brigades and production volume, remain on the initial level.

The reduction of fixed production costs (*Ks*), resulting from shortening the construction process (the "by-passed" process: 6 + 2 + 1 + 8 + 2 + 1 + 0 + 0,5 = 20,5 r–g) result from the implementation of selected, technologically possible, work operations, forming schedule activities when teams (brigades) come to a standstill – waiting the work front to become available. The representation of production downtime in network diagrams are nodes, culminating in production downtime and decelerating the manufacturing process.

The analyzed technological and organizational indifference s in relation to the predecessor – the successor can alternate between two or more of the means of production, pursuing a related technological sequence of the construction process. They can also exist in the global resource allocation analysis, both between indirect as well as direct predecessors and successors in the investment cycle.

References

[1] Biruk S., Jaśkowski P., *Scheduling of a multiple object project with continuous execution of processes on working plots*, Scientific Papers of the Higher Military Academy of Land Forces, Warszawa 2010, 114-116.

[2] Bizon-Górecka J., *Methods of risk management in construction,* Publishing House of University of Technology and Agriculture, Bydgoszcz 1998, 38-39.

[3] Chyliński P., *Analysis of influence of organizational breaks on realization cost and time of building works with permutation flow problem features*, Phd Thesis, Wrocław 2011, 19-32.

[4] Iwanow A., Szkarowski A., *Analysis of investment in construction and environmental engineering*, Publishing House of University of Technology in Koszalin 2011, 193-194.

[5] Jaworski K. M., *Methodology of design as construction progresses*, Scientific Publishing PWN, Warszawa 2009, 94.

[6] Kasprowicz T., *Engineering of construction project*, Publishing House of the Institute for Technology of Exploitation, Warszawa 2002, 151-153.

[7] Kietliński W., Janowska J., Woźniak C., *Investment process in construction*, Publishing House of Warsaw University of Technology, Warszawa 2007, 48-49.

[8] Marcinkowski R., *Methods for contractors distribution of resources in engineering and construction business*, Publishing House W.A.T., Warszawa 2002, 128-130.

[9] Marcinkowski R., Połoński M., Pruszyński K., *Monitoring and control of time buffers in the mp-kp method,* Publishing House: Naval and Geotechnical Engineering, conference publication, Gdańsk 2013, 376-378.

[10] Mrozowicz J., *Methods of building processes organization taking into account coupling of time*, Lower Silesian Educational Publishers, Wrocław 1997, 12-13.

[11] Przywara D., *Modeling of time alignment of nodal buffers in two punctual CPM network using the by-pass technique,* Publishing House: Naval and Geotechnical Engineering, conference publication, Gdańsk 2013, 388-392.

[12] Stockes E., Akram S., *Construction project management*, Publishing House Poltex, Warszawa 2010, 51.