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MODELLING AND OPTIMISATION OF PRODUCTION PROCESSES IN OVERHAUL ACTIVITIES

1. INTRODUCTION

One of the more important tasks of modelling the production or service processes is the optimisation, which often means the selection of the optimal sequence of the products or clients. In production modelling, namely, there can usually be a variety of solutions which affect significantly the techno-economic indicators of the production or service process. There are a lot of sequence varieties even when the number of products or clients is relatively small. Therefore, optimisation plays a very important role in any process modelling.

The problem of production optimisation, especially the optimal schedule of production processes is handled with great care in our country as well as in the world. In order to solve it first of all the optimisation criteria are needed. As such a criterion in solving any one of the multi-variant production task, usually the sum of production expenses is taken. Should the sequence of products processing affect only the amount of working capital, the solving may take into consideration only this value. Since the amount of working capital depends directly on the products processing cycle, the duration of the entire cycle is taken as the optimisation criterion in the modelling of the production processes.

Therefore, the production optimisation in the considered aspect includes defining of such a sequence of products processing which will render the production cycle as a minimal value. The needed optimal variant for products process initiation can be defined by calculating the production cycle duration in all the possible variants and selection of the variant which corresponds to the minimal cycle of products processing.

Such method of solving the problem is not suitable, since the number of variants in each concrete case is extremely big, even with a small number of processed products, so that the calculation of the production cycle duration, even with the aid of a computer is inconvenient. Therefore, simpler methods for solving this task need to be found.

A whole group of known methods in solving the optimisation problem can be divided into accurate and approximate methods. Two of the accurate ones need to be emphasised which can be applicable in solving the problem of production optimisation in the considered context. These are: the linear programming method and the branching and bounding method.

The accurate optimisation methods have a limited application in modelling of actual production processes, since some enable solving of small-volume tasks, and others do not exclude the complete selection. Therefore, great attention is paid to approximate optimisation methods, among them especially methods based on priority rules, the matrix and analytic methods. Characteristics and practical application of some of them will be presented in the following chapters.

2. SEQUENCE OPTIMISATION OF TWO-PHASE PRODUCTION PROCESSES

The process optimisation in this context includes selecting the appropriate sequence of serving the expected objects or clients. These tasks differ from the tasks solved by theory of mass serving in that they have a fix structure of serving means and only the sequence of serving or processing of expected objects or clients is determined.

The optimality indicators used in sequence optimisation, as mentioned before, can vary. Most commonly used is the indicator undergoing minimisation, such as the total interval duration between the beginning of the first operation in the serving sequence until the moment the last operation ends.

Analytic methods in serving sequence optimisation deal only with relatively simpler cases. The method for solving the problem where there are n served objects (clients) and two serving means (workplaces) is specially dealt with, provided that objects (clients) are served in the same order so that serving sequence is of no significance, and the total duration of serving, undergoing minimisation, is taken as optimality indicator.

This task is formulated in the following way. It is necessary to minimise the processing time of n elements (the whole cycle duration), each processed first at the first workplace (operation) in the period a_i, and then at another in the period b_i. This task is known in literature as "Bellman-Johnson's" task, and the following rule has been formulated for its solution.

From the whole set of values a_i and b_i the smallest one is selected. If it corresponds to the first workplace (operation) then the element goes first, and if it belongs to the second, it goes last. The distributed element is left out of the subsequent analyses. This procedure is repeated for the rest of the elements, until the last one from the list gets distributed. Should two or more elements simultaneously have the minimal value, the selection for their order needs additional criteria. Let us illustrate this with a concrete example.

Let us consider the workshop dealing in overhaul of navigation devices complex: inspection, repair, testing and regulation. The complex includes 8 devices (A, B, C, D, E, F, G, H). The work is done by two specialists. First every device is disassembled from the complex, inspected, tested and regulated on the testing desk in the workshop, and then re-fitted and tested within the complex. Prior to testing and regulation on the testing desk the devices do not need to be tested within the complex, therefore, device testing phases are sequential. The testing within the complex can be postponed due to the waiting for it to be tested and regulated on the testing desk in the workshop. The complex testing technology allows any sequence of testing the devices, A, B, C, D, E, F, G, H, so that it is necessary to find the optimal sequence of testing and regulating the eight devices.

Based on the data regarding duration of performing the given operations for the previous period, Table 1 is obtained.

Since optimal sequence of processing the eight elements needs to be determined, it is necessary to choose between 8! = 40 320 variants of possible sequences. The previously mentioned method of solving the problem enables a selection of such a sequence which will provide the minimal waiting time, and reduce the total duration of device testing to a minimum.

The problem is solved in the following way:

1. The table is studied where the duration of repair, inspection and regulation of the device are recorded (see Table 1) and the minimal duration searched. In the given example it is 0.5 hours - duration of testing the device C within the complex.

2. If this minimal duration is found in the first row of the table and corresponds to the first operation (testing of the device on the testing desk), then this element is taken first.

If the minimal duration belongs to the second operation (testing of the device within the complex), then this element is scheduled as last. In this example the minimal duration belongs to the second operation, therefore inspection, testing and regulation of the device C are carried out last.

Should there be equal minimal duration in both operations, the device with minimal duration of the first operation is scheduled as first, and the device with minimal duration of the second operation as last. If the minimal duration of the first operation is equal, then the element with the shorter duration of the second operation is scheduled first. Should this occur in the second operation, then the device that has shorter duration of the first operation is scheduled last.

3. The device with determined schedule should be left out of further analysis, and the described procedure applied to other devices. Thus, all devices get included in the schedule following the first device or preceding the last one. Using this method in scheduling the testing of devices from our example, the sequence would be: H, G, A, E, F, D, B, C (see Fig. 1).

The optimal sequence represented in the form of a linear diagram shows that the total duration of testing and regulating the devices was shortened to 14.7 hours, and the nonproductive time due to waiting for the first operation to end, to 5 hours.

A similar method can be applied in determining the optimal sequence of processing of any amount of elements or assemblies on two machines (workplaces). In solving the problem, similarly as in the previous one, the machine readjustment when passing from one element to another is not taken into account. When the exact readjustment time of a machine or a workplace is known, it is included in the operation structure of element processing, i.e. it is included in the productive time. Another method is also possible, when the readjustment time is consid-

Table 1 - Duration of inspection, testing and regulation of navigation equipment devices

Operation	Device symbol							
	A	B	C	D	E	F	G	H
Testing of the device on the testing desk, hours	3.0	1.2	1.0	1.6	2.5	2.0	1.5	1.4
Testing of the device within the complex, hours	1.5	0.8	0.5	1.0	1.4	1.2	1.5	1.8

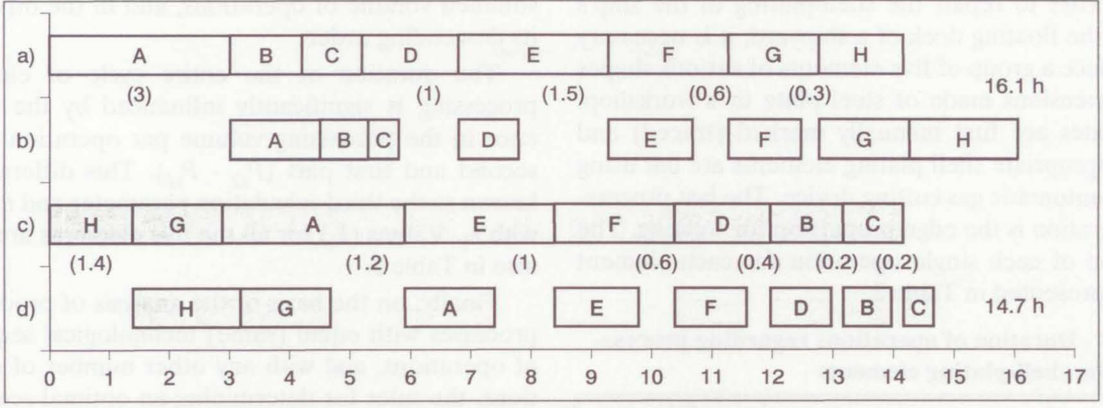

Figure 1 - Linear diagram of the testing sequence of navigation comples devices:
a - line representing testing of device on testing desk in order of their entry in Table 1;
b - line representing the testing of device within the complex in the same order;
c - line representing testing of device on testing desk at optimal sequence;
d - line representing testing of device within the complex at optimal sequence.
Note: Numbers in parentheses show the idle time - waiting for the testing of the device on the testing desk to bo completed

ered as wasteful (non-productive). When the problem is set in such a way the previously described method can be applied only for one machine (workplace). The machine readjustment is then considered as the first operation, and the element processing operation - as the second one.

Based on the previously described method, the method for solving the three-phase process has been devised, taking into consideration certain special conditions. Here also the conditions of equal processing sequence in all the three phases are retained, i.e. object (client) served in the first phase (operation), will be served at the second one, only when this one is free, and then on the third one, under the same condition. Moreover, this type of tasks sets an additional condition - meeting one of the following restrictions: - minimal serving duration in the first phase is greater or equal to the maximal serving duration in the second phase; or - minimal serving duration in the third phase is greater or equal to the maximal serving duration in the second phase. The application of this method will be illustrated in the following chapter.

3. SEQUENCE MODELLING AND OPTIMISATION OF THE MULTI-PHASE PRODUCTION PROCESSES

Among the methods regarding optimisation of multi-phase production processes, the so-called matrix method is of special interest. This method minimises the idle time of the machine (worker) and the total element processing duration at all the production cycle workplaces. By analysing the properties of non-synchronised production processes, the duration of the entire processing cycle can be defined according to the following formula:

$$T_c = \sum_{j-1}^{s-1} t_{1j} + \sum_{i=1}^{k} t_{im} + \sum_{i=1}^{k-1} t_{pim},$$

where t_{ij} - is the duration of processing of the first element at the j workplace; s - number of the last operation (workplace) in the technological processing of the first element; t_{im} - duration of the last processing operation of the i - element at m - workplace (machine); k - number of processed elements; t_{pim} - the machine non-working interval while performing the last m - operation between the finish of the processing of the i-element and the beginning of the processing of the (i+1)- element.

The previous formula shows that the duration of the entire processing cycle of elements T_c is influenced by the first and third item. Therefore, the optimisation has to minimise these two items. The core of the method is in dividing the duration cycle of elements processing t_{ij} into two equal parts regarding number of operations. The sums of operation duration of each part are called calculation parameters and marked as P_{i1} and P_{i2}.

Even number of operations:

$$P_{i1} = \sum_{j=1}^{\frac{m}{2}} t_{ij} \quad \text{and} \quad P_{i2} = \sum_{j=\frac{m}{2}+1}^{m} t_{ij};$$

and odd number of operations:

$$P_{i1} = \sum_{j=1}^{\frac{m+1}{2}} t_{ij} \quad \text{and} \quad P_{i2} = \sum_{j=\frac{m+1}{2}}^{m} t_{ij};$$

To illustrate the application of this method let us use the following example.

In order to repair the shell-plating of the ship's hull in the floating dock of a shipyard, it is necessary to produce a group of five elements of various shapes and dimensions made of steel plate in a workshop. The plates are first manually marked (traced) and then appropriate shell plating elements are cut using a semi-automatic gas cutting device. The last processing operation is the edge prepartion for welding. The duration of each single operation for each element type is presented in Table 2.

Table 2 - Duration of operations regarding processing of the shell-plating elements

Element type	Marking, min.	Cutting, min.	Edge preparation, min.
A	40	10	30
B	60	15	40
C	25	8	15
D	45	10	30
E	80	20	50

The work in the workshop is done by one group of workers whereas the other group carries out the repairs on the ship's hull in the dock. The necessity to minimise as much as possible the duration of overhaul in the dock, requires that after completing every single element it is immediately delivered to the dock in order to be fitted in and welded. Therefore, all the processing operations on all the elements have to be performed sequentially and without stopping if possible.

Since this example involves an odd number of operations, the duration of the second (intermediate) operation is included in the first calculation parameter P_{i1} and in the second P_{i2}. For element A parameter $P_{A1} = 40+10=50$, and the second parameter $P_{A2} = 10+30=40$. The calculation parameters P_{i1} and P_{i2} for other elements as well have been determined by analogy, results are shown in Table 3.

Table 3 - Calculation parameters: P_{i1}, P_{i2}, λ_i

Element type	Calculation Parameter, P_{i1}	Calculation Parameter, P_{i2}	Calculation Parameter, λ_i
A	40+10= 50	10+30=40	-10
B	60+15= 75	15+40=55	-20
C	25+ 8= 33	8+15=23	-10
D	45+10= 55	10+30=40	-15
E	80+20=100	20+50=70	-30

By analysing the properties of models, it can be concluded that the duration of the entire processing cycle is significantly influenced by the sequence of elements in the first part, in ascending order of summed volume of operations, and in the other - in its descending order.

The duration of the entire cycle of elements processing is significantly influenced by the difference in the processing volume per operation of the second and first part (P_{i2} - P_{i1}). This difference is known as the third calculation parameter and marked with λ_i. Values (λ_i) for all the five elements are given also in Table 3.

Finally, on the basis of the analysis of production processes with equal (same) technological sequence of operations, and with any other number of operations, the rules for determining an optimal sequence in elements processing are defined.

Rule I - From the given set of elements, those with the positive value λ_i are processed first, in the ascending order of their summed work volume according to operations of the first phase of the process or computation parameter P_{i1}. Elements with the negative value λ_i are taken second, in the descending order of the summed volume of operations of the second phase, that is, computation parameter P_{i2}.

By way of illustration, let us use this rule to form a version of a sequence for our example according to the data given in Table 3. Since all the elements in the given example have a negative difference of parameters P_{i2} and P_{i1} they are processed in the descending order of the parameter P_{i2}, e.g. 70>55>40. Therefore, the sequence is: E→B→D. Since the elements A and C have equal difference values (-10), the first will be the one which in the first phase of the summed process has greater parameter P_{i1}. The final sequence according to this rule is: E→B→D→A→C.

Rule II - All the elements of the second and first phase of the summed process are processed in the order of descending difference of the process volume sums per operations, i.e. in the descending sequence λ_i. According to data in Table 3 values λ_i are distributed in their descending order form the sequence -10, -10, -15, -20, -30, which corresponds to the following sequence of elements processing C→A→D→B→E.

Rule III - This rule corresponds to the first one, with the only difference that it distributes the elements in subsets - first the elements with values $\lambda_i > 0$, then elements with $\lambda_i = 0$, and finally the elements with $\lambda_i < 0$. Since our example does not include the first two categories, the sequence of elements according to this rule is equivalent to the sequence determined by Rule I.

Since the given example meets the condition - minimal duration of marking (type C element - 25 min), is greater than maximum duration of cutting (type E element - 20 min), the task can also be solved by the method devised for the three-phase processes (see Chapter 2).

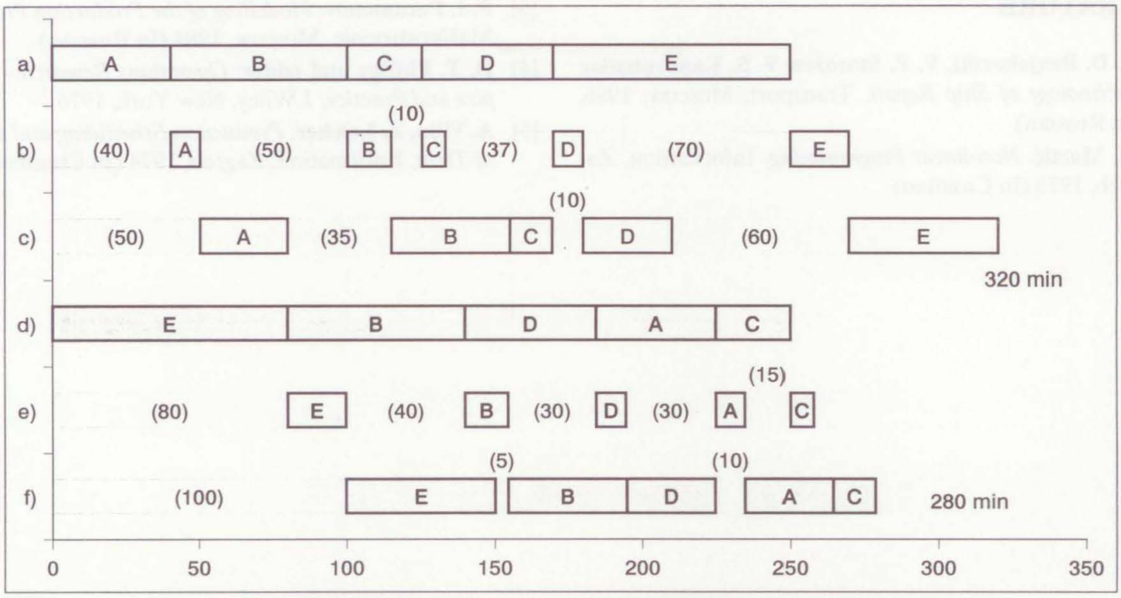

Figure 2 - Linear diagram of the sequence of the shell plating elements production: a), b), and c) - processing (marking, cutting, edge preparation) according to the preliminary sequence A, B, C, D, E; d), e), f) - optimal sequence of processing (marking, cutting, edge preparation) of plates.

Table 3 is also used for solving the task, but in this case the calculation parameter P_{i1} stands for the time standard of the first phase (sum of the standards of the first and second phase from the starting table 2), and the computation parameter P_{i2} the time standard of the second phase (sum of the standards of the second and third phase from the starting table) of the modified process. Should we apply to this modified process the rule for solving two-phase processes, in the given example, the following sequence is obtained: E→B→D→A→C.

Since the sequence according to this method is completely identical to the sequence obtained by the Rules I and III, and completely opposite to sequence according to Rule II, for the final solution of the optimal sequence in the given example the following sequence has been selected: E→B→D→A→C.

Figure 2 shows a linear diagram of the sequence of elements production according to the random (Tables 2 and 3) and optimal sequence. By accepting the optimal sequence, it is possible to shorten the production duration of all elements by 12.5%, and idling (waiting) for the operations of cutting and edge preparation by almost 15%.

4. CONCLUSION

The study and application of production optimisation methods is, no doubt, an important task in improving the production organisation. Solving this task provides objective clues in devising an optimal schedule and efficient use of all the available resources. The study and example of the application of the optimisation method given in this paper has not used all the possibilities nor presented all effects, but it obviously has its purpose and aim.

The purpose and effect of its application increases proportionally with the increase of the volume of the studied process. So e.g., if a global process of overhauling a group of ships is taken into consideration, usually consisting of overhauling a floating ship and overhaul in the floating or dry docks, the optimal sequence of ships in these two phases of overhaul will increase the productivity of the entire process, use of all the shipyard resources and reduce the total cycle, as well as the non-productive expenses because of idiling of a usually very expensive equipment.

The method of sequence optimisation described in this paper can be similarly applied in various other branches of industry or servicing. Aided by a computer, e.g. MS Excel packet, its application (calculation and graphics), it also becomes fast and simple.

SUMMARY

The paper studies the problem of sequence optimisation in overhaul activities production process modelling. Possible tasks, optimisation criteria and methods are analysed. Methods for solving two- or multi-phase production processes are illustrated on examples from practice. Special attention is paid to rules and criteria for selecting the optimal sequence in multi-phase production processes. For the given examples the optimal process sequence is presented graphically with the results analysis.

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