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DECISION MAKING STAGES IN PRODUCTION SCHEDULING OF COMPLEX PRODUCTS

In this article the issue of production scheduling in manufacturing systems characterized by discrete production flow is presented. A decision making stages taken in production scheduling of complex products as a part of the project N R03 0073 06/2009 – "Integrated, management system for variable and multiassortment production to order in small and medium-sized enterprises" supported by The Polish National Centre for Research and Development are shown. Complex product is understood as product, which can be a composition of other products, it means that in its structure assembly operations are allowed. There are following decision-making stages in proposed method that should be performed while creating a schedule: order sequencing, scheduling strategy selection, subprocesses and operations sequencing, selecting of operation variants, schedule evaluation. The "order sequencing" stage is associated with organizing the processes according to established priorities. The "choice of scheduling strategy" stage determines the way of operations introduction into a schedule. The "subprocesses and operations sequencing" stage refers to the issue of sequencing parallel operations in the structure of the process. The "selecting variants of operation" stage shows how to select alternative variants for the operation. Scoring method for assessing schedules allows carrying out the assessment process using multiple criteria and experts.

1. INTRODUCTION

Production scheduling is a very important issue from the perspective of the production organization, it allows achieving multiple benefits as costs minimizing, production cycle shortening and timely execution of orders. Scheduling is a decision-making process that deals with the allocation of resources to orders (jobs, processes, tasks) in a given time horizon and its goal is to obtain the best possible solution, according to given objective function. Determination of optimal schedules is classified as a NP-hard problem. For this class of optimization problems polynomial computational complexity algorithms probably do not exist, which practically means that (for most production systems) obtaining the optimal solution in reasonable time is not possible, due to the number of resources and tasks. Many works have been devoted to the search of algorithms, that allow finding the optimal solution [7], but the current state of knowledge and achievements in this area significantly limits their practical application to simple systems with no more than several

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tasks. Fortunately, in real production systems optimal solutions are not required. It is enough when acceptable solution is found, which meets the established goals.

This work is a part of a project of development tool supporting production management in small and medium-sized enterprises realized in Institute of Automation Processes Engineering and Integrated Manufacturing Systems of Silesian University of Technology and Institute of Engineering and Automation of Wroclaw University of Technology. The main aim of this project is to develop an integrated decision support system for SMEs (Small and Medium Enterprises) with a variable multi-assortment production. The authors plan to introduce modifications to the three independent software systems: Proedims, KbRS and SWZ. Proedims, an enterprise management system, is developed at the Technical University of Wrocław, KbRS - Knowledge based Rescheduling System and SWZ - System of order verification, are developed in the Silesian University of Technology. Creation of an integrated software environment is an alternative to expensive and very complex MRP/ERP class systems, which are not available for companies in SMEs sector. In previous stages of the project, methods and models for the exchange of data between systems for technical and organisational production planning were established. In particular, the model contains necessary details of complex products and resources. The data exchange model, based on the XML data format, has been shown in [1]. The method of a process automation of creating a neutral data exchange formats for the integrated decision-making systems in SMEs, using XML standards, XML schema and XSLT has been presented in [11]. A definition of an XML document for SWZ and KbRS systems was also elaborated there.

In this article an analysis of decision-making stages taken in production scheduling of complex products is presented. The conclusions of this work will be used to develop object-oriented model of knowledge representation of KbRS scheduling system.

2. BUILDING/CREATION OF SCHEDULES / SCHEDULES CREATION

In scheduling of complex products, both hierarchical and integrated approaches are used. In hierarchical approaches particular stages of building a schedule are treated separately, e.g. assignment of operations to machines and sequencing of operations on machines. An example of a hierarchical scheduling algorithm based on improved processing operation tree is presented in [13]. Short-time strategy and machine-balance strategy to assign operations to machines is elaborated there. To solve the sequencing problem, they allied critical path method is adopted, to confirm the scheduling sequence of operations. Operations are divided into dependent and independent ones and forward greedy rule is use in order to set completion times. An example of integrated approach, presented in [10], uses a genetic algorithm-based scheduling method of deep product structure. This includes a repair process that identifies and corrects infeasible schedules. The algorithm takes account of the requirement to minimise the penalties due to both the early supply of components and assemblies and the late delivery of final products, whilst simultaneously considering capacity utilisation. In [3] optimal and heuristic methods for solving the scheduling problems of complex products are developed. Based on the representation of assembly sequence of the products three production models are defined: production of a single product with a simple assembly sequence; production of a single product with a complex assembly sequence; and production of *N* products.

In presented work, a hierarchical approach and deterministic scheduling problem is considered. Manufacturing system is described as a set of resources $M = \{M_1, M_2, \ldots, M_i, \ldots, M_I\}$, I = number of resources; and set of processes $P = \{P_1, P_2, \ldots, P_j, \ldots, P_J\}$, J = number of orders. In this project, the following basic assumptions have been adopted:

- there is flexible job shop configuration of the production system,
- there is unlimited buffer space between resources,
- the technological process of a complex product is considered as a multi-level configuration of machining and/or assembly operations,
- operations may have alternatives in more than one resource,
- operations are not pre-emptive.

An example structure of a complex product with assembly operations is shown in Fig. 1. There are 3 subprocesses that should be finished before starting main process 1. Operations *o1, o2, o4, o5* are assembly operations.

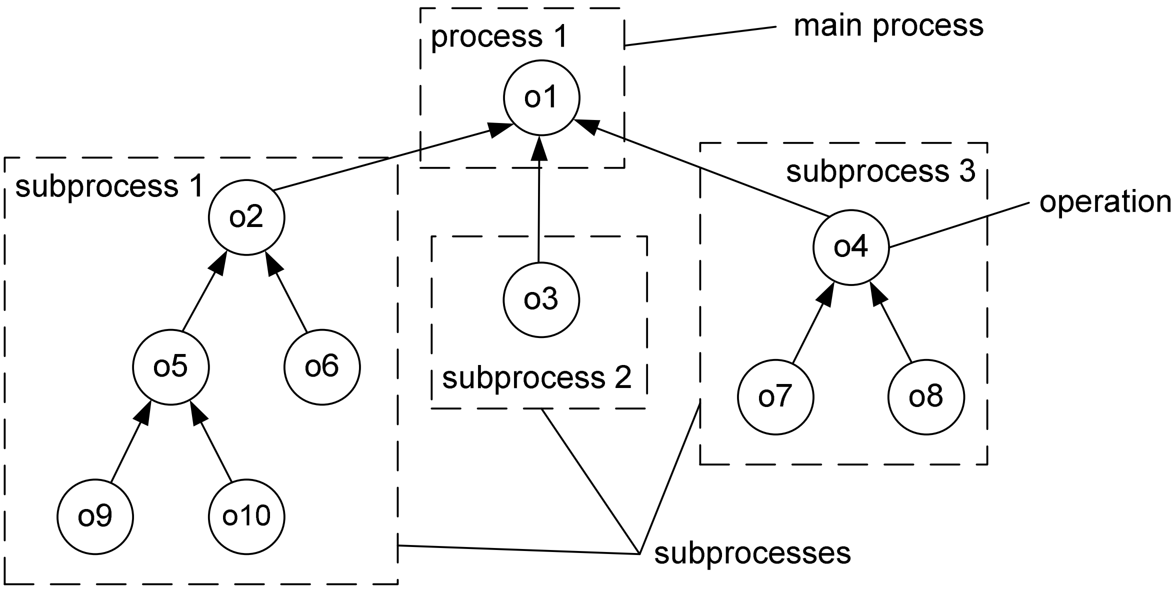

Fig. 1. The example of complex product

The creation of a single schedule for the assumed input data model involves the following decision-making stages:

- order sequencing,
- choice of scheduling strategy,
- subprocesses and operations sequencing,
- selecting of operation variants,
- schedule evaluating.

2.1. ORDERS SEQUENCING

The first step of a schedule creation is to select a sequencing algorithm. In simple systems, with a non-complex processes, scheduling problem is naturally reduced to sequencing problem. Thus, many works in scheduling area concentrates only on sequencing problem [7].

A sequencing algorithm can be understood as a priority rule that organizes the processes according to a specific index. Each algorithm uses its own indicators, based on the parameters of the processes, their operations, deadlines, etc. Although priorities of processes are arbitrary given by dispatcher, as an input data, a problem may occur when there are a few processes with the same number of priority (Fig. 2), and there are no restrictions in order of their execution.

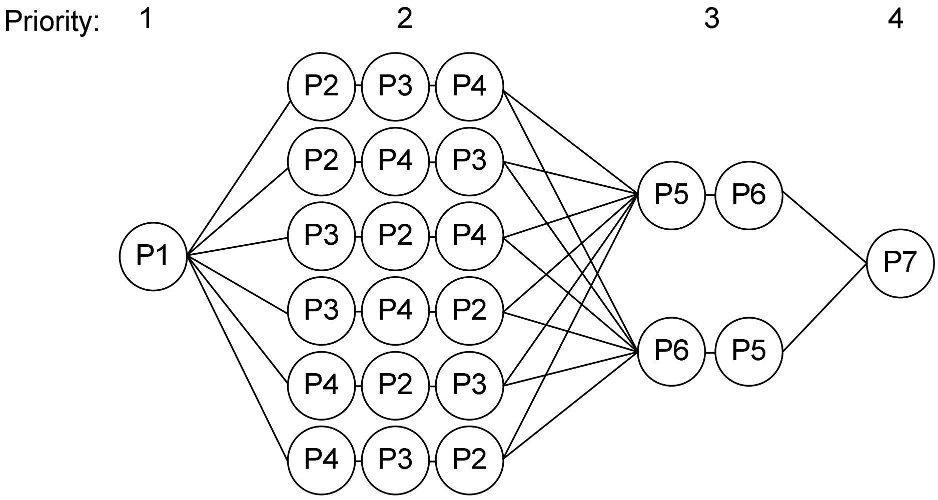

Fig. 2. Sequencing problem with equal values of processes priorities

The number of possible solutions at this stage *(os)* is calculated according to formula (1). Sequencing algorithm should use an additional rule or check each possible sequence.

$$os = \prod_{p} n_p! \tag{1}$$

where:

n_p – the number of processes with priority p

2.2. SCHEDULING STRATEGY

There are two basic scheduling strategies: *forward* and *backward*. In the case of *forward* scheduling tasks are planned at the earliest possible date for them. Operations of a process are placed to a schedule sequentially from first to last, and the time they start is restricted by release time of their process or the completion time of a previous operation. In the *backward* scheduling, tasks are planned in such a way that they end in terms or as close as possible to the deadline. Operations of the tasks are planned from the last to the first. The time when an operation should be finished is restricted by due date of the process (last operation in a process) or beginning time of the next operation in the process.

The choice of strategy depends on used performance measures, deadlines, priorities, work in progress costs and inventory, etc. Forward scheduling, a method which guarantees the execution of the process as soon as possible, is often used for urgent tasks. However, too early termination of a process may significantly increase the costs. Backward scheduling method is applied in cases where it is important to finish a process just in time. This method is used most often when too early execution is not recommended (e.g. capacity limited storages, freezing of capital, losses due to storage of materials, reducing usefulness period, product deterioration).

Chosen scheduling strategy requires application of the proper algorithm responsible for ordering operation that are inserted into a schedule. Presented in this paper complex product has an in-tree graph structure. Therefore, in the case of forward strategy the algorithm based on depth-first search (DFS) is suitable. In DFS algorithm, searching starts from the root node and moves down to the very end of branches, then returns one level and tries another branch, etc. An example sequence of operations of process shown in Fig. 1, processed by DFS algorithm, is *{o9, o10, o5, o6, o2, o3, o7, o8, o4, o1}*.

In the case of backward strategy, the algorithm based on breadth-first search (BFS) is suitable. In BFS searching begins at the root node and explores all the neighbouring nodes. Then for each of those nearest nodes, it explores their unexplored neighbour nodes, and so on, until it finds the goal (here: visit all the nodes). An example operations sequence of process shown in Fig. 1, processed by BFS algorithm, is *{o1, o2, o3, o4, o5, o6, o7, o8, o9, o10}*.

2.3. INPUT SEQUENCING OF PARALLEL SUBPROCESSES AND OPERATIONS

Application of DFS and BFS algorithms determines only an overall way of operations sequencing. The final arrangement of operations depends on the order of examining parallel edges in the graph. In DFS and BFS child nodes obtained by expanding a node are added according to a FIFO queue. Exampled sets of operations, which at first can be executed, are shown in Fig. 3.

A set of possible operations to introduce is changed each time after removing an operation placed in the schedule. According to the structure in Fig. 3 - forward scheduling - it can change as follow:

1: {o9, o10, o6, o3, o7, o8} – selected o6,
2: {o9, o10, o3, o7, o8} – selected o9,
3: {o10, o3, o7, o8} – selected o10,
4: {o5, o3, o7, o8} – selected o7,
5: {o5, o3, o8} – selected o8,
6: {o5, o3, o4} – selected o5,

7: {o2, o3, o4} – selected o2,
8: {o3, o4} – selected o3,
9: {o4} – selected o4,
10: {o1} – the final operation.

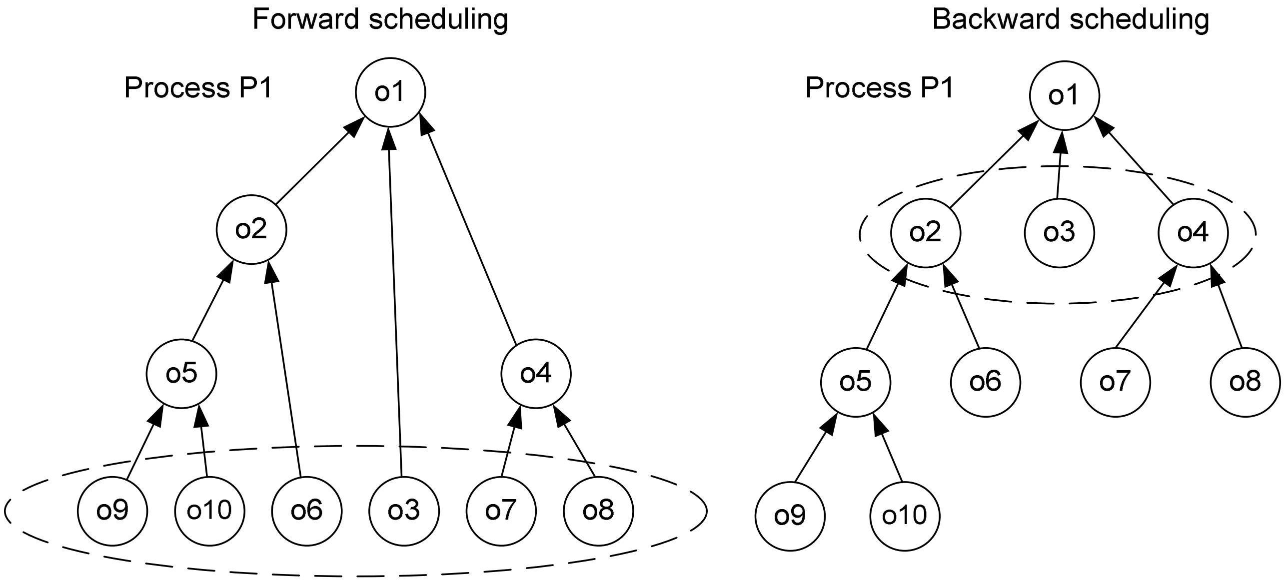

Fig. 3. The first stage of nodes sequencing problem in a complex product

Finding the optimal sequence requires a complete review method, because it depends strictly on the distribution of earlier operations in the schedule and expected objectives. Besides, a local optimum in this case does not guarantee global optimum - a solution, which is locally worse, may have a better impact globally, after the construction of the entire schedule.

2.4. OPERATIONS VARIANTS

Technological capabilities of manufacturing systems allow the creation of many different technological processes for the same item. The differences may relate to technology implementations, the order of implementation of certain procedures (operations) and times (duration of the treatments, the setup times, etc.) related to the possibilities of resources, used tools and equipment. The technological process with more than one variant of the implementation in the production system is defined as the multivariant technological process [5]. The current situation in the production system and a set of evaluation criteria in a particular situation should help in deciding on the selection of the best possible option for execution. The traditional approach to the design of technological processes with optimization of a fragmented approach, ignoring alternatives, significantly reduces the flexibility of its implementation. On the other hand, multivariant technological processes development, under the conditions without computer support, may prove to be too time-consuming and unprofitable, especially when a large number of possible variants can be obtained. The CAPP systems (Computer Aided Processes Planning) do not have these restrictions. The method of integration of multivariant technological processes planning and scheduling has been described in [2].

A multivariant technological process allows realising some operations in more than one variant v_a: $V = \{v_1, v_2, \ldots, v_a, \ldots, v_A\}$. The operation variants can differ in the resources (different route), used tools, or instrumentations. During the schedule construction phase, it should be decided which variant of operation is most preferred. Of course, as at previous stage, local optimum does not guarantee the global one. The best variant of an operation can be selected by many criteria, as min. cost, min. operation time, min. setup time, min. starting or min. finishing time of operation [6]. Generally, the objective function is expressed as follows:

$$\min_a\left(\frac{z_a^{tb}}{w_{tb}^z} + \frac{z_a^t}{w_t^z} + \frac{z_a^{ts}}{w_{ts}^z} + \frac{z_a^c}{w_c^z}\right) \tag{2}$$

where, z^{tb}_a – starting time coefficient of the operation variant a, z^t_a – processing time coefficient of the operation variant a, z^{ts}_a – setup time coefficient of the operation variant a, z^c_a – cost coefficient of the operation variant a, w^z_x – weights assigned to coefficients above, $x = \{tb, t, ts, c\}$.

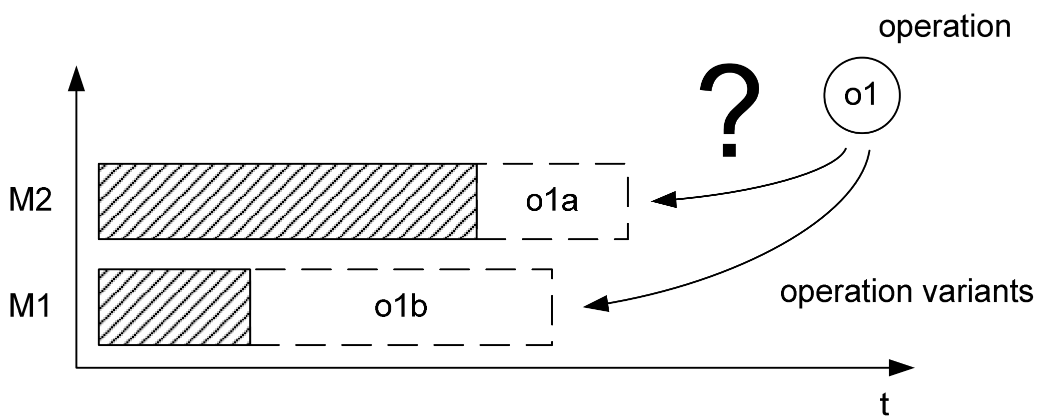

Fig. 4. The problem of operation variant selection

The normalized, starting time coefficient (z^{tb}_a) depends on the method of scheduling:

$$z_a^{tb} = \begin{cases} \dfrac{tb_a}{\max_a\{tb_a\}}, & \text{in case of forward scheduling} \\ \dfrac{\min_a\{tb_a + t_a\}}{tb_a + t_a}, & \text{in case of backward scheduling} \end{cases} \tag{3}$$

The other coefficients:

$$z_a^t = \frac{t_a}{\max_a\{t_a\}},\ z_a^{ts} = \frac{ts_a}{\max_a\{ts_a\}},\ z_a^c = \frac{c_a}{\max_a\{c_a\}} \tag{4}$$

where, tb_a – beginning time of operation variant a, t_a – processing time, ts_a – setup time, c_a – overall cost of operation variant.

The way of selecting the appropriate option is to schedule temporarily each possible operation variant and compare results.

2.5. SCHEDULE EVALUATION

Manufacturing systems are designed to meet the demands efficiently. Many works relate to the schedule evaluation, where a complete overview of this domain can be found [9],[12]. In [4] a number of different considerations that must be taken into account when assessing the quality of scheduling has been described. Performance of production in real manufacturing systems flow is usually measured by more than one criterion. It should be considered in evaluation process. Moreover, decision-making process depends strongly on human preferences, so in many cases it is trade off between different experts opinions. Each of the expert group may indicate a different subset of relevant criteria, as well may also choose different weights to individual criteria.

The construction objective for schedule evaluation is preceded by following stages:

- defining the set of *R* evaluation criteria *(K)*,

$$K = \{K_1, K_2, \dots, K_r, \dots, K_R\} \tag{5}$$

- appointment the group of *X* experts *(E)*,

$$E = \{E_1, E_2, \dots, E_x, \dots, E_X\} \tag{6}$$

- assigning the importance of opinion (weight) for each expert (w^e_x).
- creating the subset of criteria for each expert (K^e_x),

$$K^e_x \subset K \tag{7}$$

- assigning of the weights for each criterion, given by each expert $(w^k_{x,r})$,

After inserting all the operations, a complete schedule should be evaluated. The overall evaluation of a schedule is calculated by aggregating its partial evaluations. The following formula is used:

$$U_h = \sum_x \sum_r w_x^e w_{x,r}^k u_{h,r} \tag{8}$$

where:
h – number of a schedule, $(h = 1, \ldots, H)$. H – the number of generated schedules,
$u_{h,r}$ – partial evaluation of schedule h by criterion r,
The best schedule is obtained by following objective function:

$$\max_h \{U_h\} \tag{9}$$

The process of scheduling automation using computer software allows creating a schedule without any human assistance. Manufacturing practice, however, shows that the planner/dispatcher eventually adjusts the schedule prepared this way. Therefore, the result of the proposed scheduling method is not a single schedule but the fixed-length list of schedules (ranking list), in accordance with the adopted objective function. The final decision on the selection of a schedule for the implementation to the system takes the dispatcher, who can choose other than first in the solution list.

3. SUMMARY

Presented methodology of production scheduling is focused on supporting effective decision making in the verification of production orders and optimizing the production flow. The proposed model of a complex process and the flexible job shop configuration of the production system, with the support both machining and assembly operations, is highly versatile. For this reason, it can be applied in manufacturing companies of different industries with a discrete flow of products.

Described model of a complex process can be simplified and some of the presented decision-making stages, depending on the configuration of the production system, may be omitted. This situation occurs when, for example all adopted processes have different priorities (there are no processes with the same priority), or there are not alternatives to operations.

Method of determining the best variant of the schedule should take into account the value of time and cost based criteria for a specific decision-making situation. It means that set of criteria and their weights may be changed at the time.

Computer aided production scheduling can dramatically reduce the time-consuming search for a solution, especially in systems with large numbers of resources and processes. It also enables, through simulation, analysis of production capacity and a response to a number various questions, such as: “What to produce? What kind of processes should be taken? Is this customer order worth our attention? What is the real deadline for the implementation of a specific order? How many can be produced with existing constraints? When ordering supplies, raw materials?”, etc.

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