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Assessment of planning methods at job-order manufacturing facilities

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Abstract. An approach to assess the efficiency of solving the problem of production planning at job-order small-scale manufacturing is presented. In consideration of their dimensionality, initial data are analyzed to build an optimal plan based on known scheduling methods for the production of different types. Reducing performance time of production plans by 10 % at the increase in the size of the order with technological operations for processes of different types at the use of directed exhaustive methods is shown.

1. Introduction

The use of digital technology in the development of production plans at all levels of enterprise management requires the use of effective planning methods that ensure the construction of accurate plans for a reasonable time. Production plans at all levels of production management are based on determining the total volume of production to achieve the required level of sales, productivity, time of order execution. The requirement for accurate production planning is particularly relevant for small-scale customized production. It takes the order as a planning and accounting unit. In its structure at the manufacturing of hi-tech knowledge-intensive production in most cases includes one product with a complex structure. Such a product consists of a large number of parts and assembly units (DSE), a wide range of materials, purchased components (PKI) and tools. The number of DSE and PKI names in a product can reach several tens of thousands. This significantly complicates the control over the execution of the order, which is carried out according to the expanded planned indicators.

2. Tasks and methods of planning for job–order manufacturing facilities

The main criteria of optimality in scheduling for any type of production are minimization of production system uptime, minimization of downtime of equipment/workplaces, optimization of capacities [1]. To create the production schedule it is necessary to determine the order and time of beginning and end of each technological operation in the production hall, as well as the execution of each technological operation according to the technological route, processing of each product at all machines. The choice of a certain order of technological operations by workstations should reduce the total time of order production, reduce downtime of technological equipment. At the same time, the problem of production planning is solved as a global multi-criteria optimization task. Its solution should ensure the search for the global extremum of the target function. This, in turn, requires the setting of a planning problem for custom small-scale production with the development of a complex criterion of optimality [2] and the development of appropriate methods of production planning for its solution [3].

Traditionally, production schedules are divided into several classes [4, 5]. Each of them implies a specific group of production planning methods:

- "Flow shop" fixes the order in which the machines are used and assumes a consistent multistage execution of each requirement on each machine in a given order. The solution of the problem is such a sequence of requirements, which minimizes the utility time [6].
- "Open shop" assumes multistage fulfillment of each requirement on a given subset of machines in an arbitrary order. The tasks of this class have the same description as in the flow shop. The only difference is that there are no precedence relations between operations. In other words, the number of operations for each requirement is the same, but the order of their execution may differ for some requirements.
- "Job shop" sets for each requirement a fixed order of execution on a given subset of machines. In this case, there are no precedence relations between the individual requirements, the number of operations in different requirements may differ.
- "Release dates" class assumes that service times are set for each requirement, as well as fixed dates for its receipt and completion. In contrast to multistage tasks, requirements in this class can be performed on one machine. For this reason, interruptions and arbitrary order of the requirements are allowed. If several variants of schedules that meet the specified prescriptive deadlines are obtained, a schedule with the minimum total number of interruptions is chosen as the solution.
- "Single machine" is the class for production planning a single workplace. It is basic for developing planning algorithms in complex cases.
- "Parallel machines" are a type of production both with similar jobs with similar parameters and with different parameters, but with the same purpose.

At the present stage in production planning for the methods used to obtain production plans, it is possible to distinguish several classification features for the evaluation of the method when choosing a solution to the planning problem. The choice of an effective method of planning when forming a plan at different levels of production management is especially relevant for small-scale custom production. For them, it is important to receive plans both enlarged and accurate in conditions of a frequently changing order portfolio within a reasonable time.

The main classification features of planning methods: by used mathematical tools [5]; by accuracy; by computational complexity.

Classification of planning methods by the mathematical tools used:

- Heuristic methods (including probability algorithms and local search) based on plausible but not mathematically grounded assumptions about properties of the optimal solution of the problem [4]. In essence, heuristic algorithms take into account one or more properties of the optimal solution, based on which the search for possible solutions is reduced.
- Discrete programming methods based on the procedure of searching the whole range of acceptable integer solutions.
- Evolutionary methods.

Classification of planning methods by accuracy:

- Accurate methods - complete search algorithms or using different techniques to reduce the search. The result is always an optimal solution.
- Approximated methods - limited search algorithms based on any knowledge of the properties of the optimal solutions.

Classification of planning methods by computational complexity:

- Polynomial algorithms.
- Pseudo polynomial algorithms.
- Exponential algorithms.

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The review shows that the tasks of production planning belong to the NP-class of complexity. It is impossible to find their exact solution in a reasonable time.

3. Assessing the effectiveness of planning methods

To solve the problem of planning on the order small-batch production with the participation of authors a software library was developed. Its general structure is shown in figure 1. The library for flow shop production includes the following methods: branches and boundaries [7]; Petrov-Sokolitsyn [8]; five generalizations of Johnson [9]. For open shop production methods of planning based on the genetic algorithm [10] and the approximation algorithm [11] are presented.

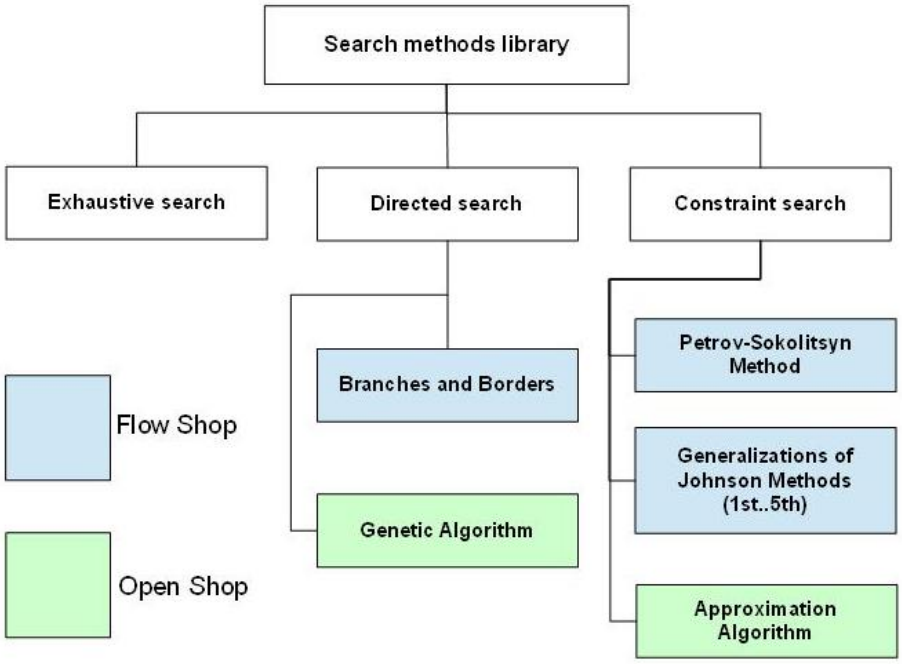

Figure 1. Software library methods for operational planning.

As the initial data for each of the planning methods, the library uses a matrix, whose elements are the execution time of a technological operation at the machine (for example, the time of machining the part). Figure 2 shows the general structure of the library of planning methods for "open shop" and "flow shop" production.

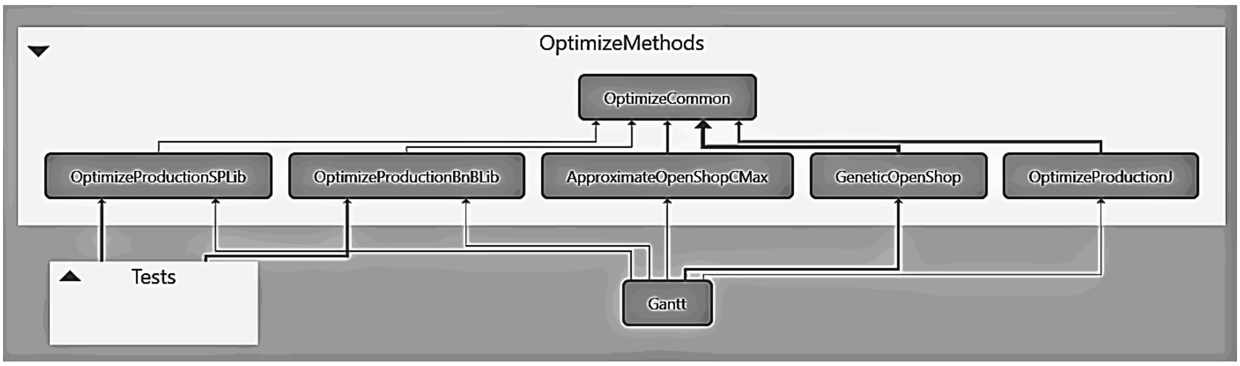

Figure 2. Program implementation of the library of planning methods.

The following test data were used to test planning methods to assess their effectiveness. We consider the technological processes of order execution at 20 machines for in-line production with the time of technological operations in three ranges: from 0 to 5 conventional time units, from 0 to 50 and from 0 to 100. These ranges correspond to productions of different types.

Input data was generated to assess the effectiveness of planning methods. In the first step, from 0 to 50 operations are performed for production processes of various types. On the next steps of the experiment, the initial data were generated in the same way, i.e. with the step of 50 technological operations. This made it possible to obtain the maximum size of the planning task when selecting the optimum process to start queues for manufacturing from $(300!)^{20}$ queue variants. By denoting m – number of jobs and n – number of process steps, we obtain an expression to calculate the number of variants of queues Q. This can be represented as follows:

$$Q(m,n)=(n!)^{m} \tag{1}$$

The matrix for the initial data was filled with random values of the times of technological operations in the mentioned ranges and calculations for scheduling were made. The results of calculations in the form of operating time of the production system (in conventional units) are given in tables 1-3 for technological operations with the execution time in three ranges specified above.

Table 1. The results of the planning algorithms functioning at execution time of technological operations in the range of 0 to 5 conventional units.

	PetSok[a]	1st GJ[b]	2nd GJ	3rd GJ	4th GJ	5th GJ	BnB[c]
50	215.36	220.53	219.55	221.57	225.58	218.59	206.26
100	388.78	388.79	389.81	388.85	391.87	388.88	379.27
150	535.01	535.03	541.04	528.05	543.06	548.06	522.91
200	678.13	677.14	691.14	681.16	698.17	682.19	663.12
250	808.24	815.25	810.3	806.32	814.33	801.34	773.32
300	947.47	948.49	934.49	959.51	982.52	953.53	881.02

[a] Petrov-Sokolitsyn method
[b] Generalization of Johnson method
[c] Method of branches and borders

Table 2. The results of the planning algorithms functioning at execution time of technological operations in the range of 0 to 50 conventional units.

	PetSok	1st GJ[b]	2nd GJ	3rd GJ	4th GJ	5th GJ	BnB
50	2443.61	2461.62	2421.63	2518.63	2402.64	2397.64	2311.29
100	3896.72	4003.73	3785.73	4007.74	3903.75	3897.75	3650.38
150	5400.80	5425.80	5567.81	5366.82	5491.83	5431.83	5109.10
200	6742.87	6994.88	6912.88	7150.89	6725.90	6919.91	6450.81
250	8285.85	8339.96	8485.97	8459.98	8287.99	8220.02	7903.16
300	9843.10	9864.11	9931.12	9896.18	9928.19	9707.20	9149.84

Table 3. The results of the planning algorithms functioning at execution time of technological operations in the range of 0 to 100 conventional units.

	PetSok	1st GJ[b]	2nd GJ	3rd GJ	4th GJ	5th GJ	BnB
50	4696.29	4852.3	4630.31	4655.32	4963.32	4796.33	4571.37
100	7957.4	7932.41	8030.42	7953.43	8157.43	7993.44	7821.52
150	10965.47	11032.47	11192.48	11213.48	11008.49	11093.5	11052.05

200	13712.56	13904.57	14189.57	13730.58	13904.59	14096.6	13462.59
250	16791.81	17199.82	17266.83	17143.84	16836.36	16831.86	16234.38
300	19994.88	20447.89	20158.9	20741.91	20354.92	20339.93	19119.06

Figure 3 shows diagrams of the time dependence of order execution on 20 machines for technological processes from 50 to 300 process operations.

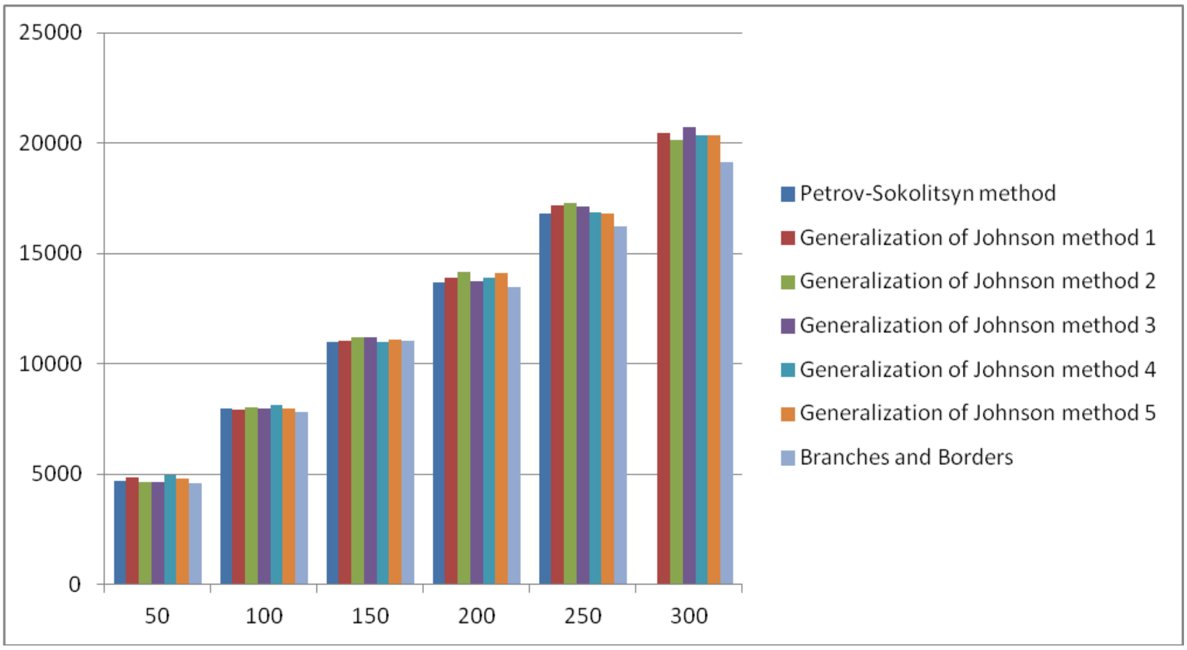

Figure 3. The dependence of the order execution time on the number of technological operations.

The duration of technological operations in the composition of the studied technological processes is in the range from 0 to 100 units of time, which is typical for modern discrete production facilities with a predominance of assembly processes.

4. Conclusion

The computer experiments carried out based on the implemented planning methods have shown that the efficiency of limited and directed search methods in the construction of order production schedules depends on the type of technological processes within the order and its size. For orders with the number of operations from 0 to 100, the difference in execution time of plans based on limited and directed search methods for technological processes of different types is 3%. Also, for orders of large size with blank, machinery and assembly processes, the execution time of production plans obtained on based onrected search methods is reduced by 10-15%.

Acknowledgments

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