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Investigation synchronous planning methods efficiency in small-batch make-to-order production

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Investigation synchronous planning methods efficiency in small-batch make-to-order production

E E Noskova, D V Kapulin and P A Russkikh

Siberian Federal University, 79, Svobodny Ave., Krasnoyarsk, 660041, Russia

E-mail: enoskova@sfu-kras.ru

Abstract. Lack of effective planning methods is one of the reasons for uneven use of production capacity, the occurrence of unplanned downtime and various types of losses. Small-scale make-to-order productions are characterized by weak workplaces specialization, by the versatility of the equipment used with a wide range of used components. They differ in the presence of repeated processing of part at the same workplaces and in occurrence of "a return flow" in a production system. The article discusses the features of planning due to technological specifics in such enterprises and a significant number of applicable incoming nomenclature items. Existing systems of production planning such Manufacturing Execution System and Advanced Planning & Scheduling System are compared, variants of their algorithmic implementation are proposed. The authors investigated the effectiveness of the application of the developed algorithms for different planning levels – interdepartmental and shop, depending of the size of order book and number of technological operations. The analysis of the conducted research allows us to assert that to provide synchronous scheduling in make-to-order small-scale productions it is necessary to apply combined planning approach using APS- and MES-technologies together.

1. Introduction

Flexible, customer-oriented manufacturing is a key concept in factories of the future. The organization of production of this type is due to modern objective trends in both technological and social development. The limiting case of such production is make-to-order single production of a full cycle, in which the product in its current form is developed and produced once. A more common case is make-to-order production, within which a certain variable range of products is developed, produced from a set of unified combinations of materials, parts and assembly units that form a set of modules [1].

It is tall order to form optimal production plan in the manufacture of products with a complex composition for small-scale make-to-order manufacturing. Each production nomenclature has its own manufacturing route but while simuhancous production of various orders their manufacturing routes intersect. In the case, the technological process can be built in such a way that to perform the next technological operation the part or assembly unit is re-processed at one and the same workplace. It result in return streams in the structure of material flows and significantly complicates production planning tasks [2].

Small-scale make-to-order manufacturing is characterized by high versatility of the available equipment park but also rather low job specialization compared to mass or large batch productions. This leads to the following features which should be taken in account when solving problems of production planning:

- the planning unit is an order;
- order management starts with design and technological preparation of production and is completed by handing over the product to the customer;
- production plan is drawn up in accordance with the order book, the order of their completion, expiration dates and the loading of manufacturing;
- when developing operational plans and issuing replacement tasks there is no accurate information on the duration of technological preparation of production;
- assignment of nomenclature to production workshops is temporary and depends on equipment load and order book.

Efficiency of planning is aimed at reducing of operating cost while improving the quality of products [3]. Therefore, the task of scheduling is to group orders to launch in such a way as to provide the best combination terms of production of orders with uniform loading of the main workshops. Changes in production volumes and the range of components lead to constant adjustments to the production plan, the use of "manual" control methods, entail uneven and ineffective capacity utilization, irrational use of resources, work in an "emergency" mode, etc. To ensure the reliability of in-house logistics processes in the context of the development of make-to-order production, it is necessary to adopt synchronous planning methods, the introduction of digital planning tools and control the traceability of product components in production. Since the planning processes of make-to-order production are the link between product development and its manufacture, one of the key factors in reducing the number of losses and costs is the use of synchronous planning.

2. Production planning technologies

Currently, modern production methodologies planning implemented by various classes of information systems. At figure 1 are levels and their corresponding production planning systems. Planning systems differ from each other in the used planning and accounting units, the composition of the planning standards, methods of planning, accounting, control and regulation of production and the procedure for registration of planning and accounting documentation [4]. Key technologies aimed at forming optimal production plans at different levels of control for custom small-scale manufacturing are manufacturing planning technologies MES (Manufacturing Execution System) and APS (Advanced Planning & Scheduling).

The purpose of the APS technology is to plan all work in time at the interdepartmental level for the enterprise as a whole. In this case, the calculation of the plan is carried out for the entire portfolio of orders, taking into account the load of production capacities. Volumetric economic indicators (production time, number of items in delivery, etc.) come to APS from ERP systems. The result of APS planning is a detailed work schedule for the entire fleet of equipment on the entire portfolio of orders for a certain period of time, for example, two to three months. An important task solved by APS technologies is the recalculation of the production schedule (rescheduling), due to the appearance of new orders [5]. Rescheduling in APS does not apply to those assignments that have already been issued to workshops earlier. New orders are placed both on the free stock of equipment and in the remaining time stock of the equipment already in use, to optimize the equipment downtime during the execution of the current order book.

The purpose of MES planning is operational scheduling at the workshop level with an increase in capital productivity of technological equipment by optimizing the shop routes of movement of parts and assembly units, strictly regulated by technological processes. The tasks solved by MES are the implementation of production volumes set by the upper level of control from the APS systems and optimization of equipment operation schedules in order to load technological and auxiliary equipment, reduce the duration and number of changeover operations, and reduce the total duration of the production cycle[6]. The result of using MES technologies is an increase in the throughput of the production system, an acceleration of the turnover of material assets and resources, which is one of the main requirements

of modern production, characterized by a small-scale nature of the production of products in a market economy.
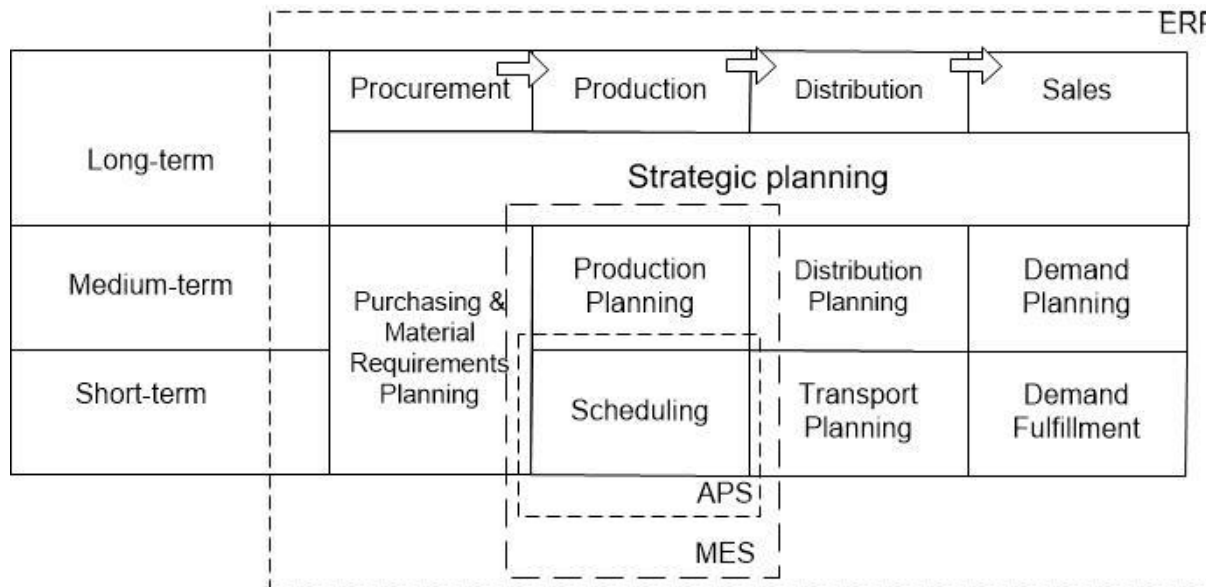
Figure 1. Levels and their corresponding production planning systems.

The MES and APS algorithms differ in the formulation of the planning problem, optimality criteria and the mathematical apparatus used to solve the planning problem. Algorithms of APS-planning as initial data use a lot of technological operations for the whole set of manufactured products, take into account a lot of technological equipment, workplaces, restrictions on each product in terms of production time, material availability, etc. Restrictions are divided into important and not so. In the first pass of the APS scheduling algorithm, a schedule is drawn up taking into account the feasibility of important constraints, for example, with no violation of delivery times [7]. If the schedule is formed, then it is considered valid and is taken as a baseline for further improvement - on subsequent passes of the algorithm, an attempt is made to take into account the remaining less important constraints.

The APS-planning task can be viewed as a global optimization problem, for example, a vector criterion for minimizing the time of order or order book production [8]. It is impossible to find the optimal result for a plan for the productions of order book in a reasonable period of time even with modern computing powers. That is why the main methods used in APS- technologies of production planning are directed search methods based on evolutionary methods: ant colony optimization method, annealing method and others [9].

3. Investigation of APS and MES algorithm implementation options

The study of algorithmic annealing method is carried out as an algorithm of APS-planning to obtain the production schedule of equipment and loads workplaces with in the whole enterprise when executing an order or order book, changing order i.e. embedding a new order into existing order book. For this purpose, the following algorithms have been implemented:

- generalized APS-planning algorithm when forming a production plan;
- generalized APS-planning algorithm when forming a production plan with a modified order book;
- an algorithm for generating and adjusting the route of filling jobs when forming a production plan.

To assess the effectiveness of the algorithms, we analyzed the preparation of plans for orders of raryinges degrees of complexity with the quantitative characteristic of the technological composition given in table 1. The results of the study of the algorithms are given in table 2.

Table 1. Specifications of orders.

Name	Quantity of assembly levels	Quantity of Blocks	Quantity of Details	Quantity of technological operation	Quantity of Workplaces
Order: 000001	3	6	24	524	68
Order: 000002	7	38	103	1590	117
Order: 000003	5	50	263	3863	212

Table 2. Investigation results of APS-planning algorithms.

Name	Initial temperature	Lead time order (before/ after optimization)	
		before	after
Order:: 000001	100	41.77	27.16
Order:: 000001	200	41.82	25.46
Order:: 000002	100	19.11	14.40
Order:: 000002	200	20.57	14.21
Order: 000003	100	744.89	622.67
Order:: 000003	200	737.19	565.05
Order book: 000001, 000002	100	48.42	33.06
Implementation: 000001, 000002, 000003	100	611.57	596.04

Analysis of the plans obtained in APS planning showed that an order can have both a long production time, but at the same time a simple composition and a small number of technological operations, and a short execution time, but a complex composition and a large number of technological operations. Orders of the second type will be optimized for a longer time, but the resulting lead time will be disproportionately less than when optimizing the plan for orders of the first type.

MES-planning methods can be classified by the mathematical tools – heuristic algorithms, discrete programming methods, evolutionary algorithms; according to their accuracy – exact algorithms and approximation algorithms; according to their computational complexity-polynomial algorithms, pseudo polynomial algorithms, exponential time algorithms [10]. To solve the problem of job shop scheduling it is proposed to use a library of MES-planning methods, which includes methods combinatorial optimization: branches and borders; Petrov-Sokolitsyn; five generalizations of Johnson. To evaluate the effectiveness of the algorithms, experimental data of work planning at 20 workplaces were used when performing at each workplace from 0 to 300 technological operations in accordance with the specified technological processes. The planning results in the form of the execution time of shop routes (in convertional units) are given in table 3.

The developed algorithms of MES/APS planning are experimentally investigated in the subsystem of synchronous planning of order-by-order production of radio-electronic equipment of the enterprise of JSC «NPP «Radiosvyaz» (Krasnoyarsk, Russia).Computational experiment to form optimal MES-plans based on implemented methods show that efficiency of bounded and directed enumeration methods when making an order production schedule depends on technological process type as part of the order and its size. For small orders with the number of technological operations from 0 to 100 difference in execution time of plans obtained on the basis of bounded and directed enumerate types is 3%. For orders of large size (100 and more technological operations) the execution time of production plan obtained on the basis of directed methods is improved by 10-15%.

Table 3. Investigation results of MES-planning algorithms

Operati-ons	Algorithm						
	Petrov-Sokolitsyn method	1st Generali-zations of Johnson method	2nd Generali-zations of Johnson method	3rd Generaliza-tions of Johnson method	4th Generaliza-tions of Johnson method	5th Generaliza-tions of Johnson method	Method of branches and borders
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

4. Conclusion

Planning and control on the modern custom small-scale productions should be carried out by combining features of APS- and MES- technologies. Research results show that both approaches should be taken to provide flexibility of planning. Cumulative increase in planning efficiency at the interdepartmental level is up to 40%, and at the inter-shop level is up to 10-15%.

At the same time, two main tasks of production planning are solved:

1. Production planning at the inter-shop level, which answers the question: is it possible to fulfill the order in the scheduled time with the existing capacity utilization?
2. Scheduling at the shop level in order to distribute the planned shift-daily tasks, taking into account the current situation, for example, unscheduled equipment downtime.

These tasks and the methods that implement them should be used to implement synchronous production planning approaches. A high effect is achieved in the conditions of order-based production of complex products with a wide range of incoming parts and assembly units.

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