Theoretical and Practical Aspects of Operational Planning for Industrial Enterprises

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Abstract— The article considers the issues related to the use of mathematical tools in the form of methods and models in drawing up production schedules for production floors at industrial enterprises, which, to a large extent, depend on optimal employment of the resources available. The models that have been suggested take into account various technical, technological, economic and business features of production. This model is distinctive due to its multicriteriality. At the same time, in order to simplify the process of production schedules elaborating, the paper proposes a statistical model that enables to facilitate operational plans and to consider, without loss of quality, the entire variety of business and economic production parameters.

Keywords— Operational planning, mathematical and statistical models, profitability of production, production plan, economic and mathematical model, production scheduling.

I. Introduction

THE most important factors of successful industrial production are modern management technologies. These are business and technological processes, standards of project management, document circulation, organizational, functional, and organizational structures, service-oriented architecture, architecture of information systems and technology architecture. One of them is operational planning as a function of production management. The basement of enterprise architecture is business and technology processes. Operational planning occupies one of the central places in the management of the business and technological processes.

Operational planning is a detailed development of plans of the company and its subsidiaries. It combines:

1. Operational scheduling, including details of the current plan of the enterprise and bringing jobs to each department, division, section, brigade working. Plans and schedules in this case are for a month, decade, day shift, and sometimes every hour;

2. Operational scheduling, which provides:

a. A continuous control over the production process and operational troubleshooting and failures at each workplace;

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b. The organization of delivery for jobs of raw materials, blanks and tools; export of finished products, waste production; functional testing of equipment; supply of energy, fuel, compressed air; organization of quality control.

There are the following types of operational planning:

1. Interplant operational planning provides coordinated activities and the necessary production proportions between the shops of the enterprise in accordance with the sequence of processes and taking into account the functions of the main and auxiliary, side and service shops;

2. Intrashop operational planning performs work on the distribution of sites and jobs. The main task of distribution is ensuring full and clear assignments of the production program and saving smooth operation of the enterprise, its shops, sites, teams of workers.

This article focuses on the following three tasks: definition of the objects sizes of labor parties launched into production; assignment of jobs to work centers (jobs); definition of the launch party objects for processing.

The most important tool for effective planning includes drafting calendar schedules (construction schedules calendar) of the plants (sites) where it is necessary to solve the problems mentioned in the same complex.

Drafting calendar schedules in the industry has its own characteristics:

this process is time consuming, that is, too large number of orders with complex technological processes should be linked in time and space;

- lack of automation of the process of drawing up calendar schedules;
- if any part of the schedule as a result of violations in the production is not met, the rest of it can lose all meaning, which leads to time consuming corrections of the plan or its complete revision.

Efficiency of an industrial enterprise depends directly on its production and economic management system and, to a large extent, on its in-house operational planning. Competitiveness of an enterprise is strongly dependent on how flexibly production planning reacts to a change in market conditions.

In the current market conditions, the following factors considerably increase the role and significance of in-house operational planning for many important management activities: focus of production on demand [1]; quick reaction to change in demand through modifying the line of goods and production output volume; possible deviation of the actual production process from operational schedules. These factors are especially difficult to consider in recurring production.

Today we have accumulated a wide range of economic and mathematical models and methods of operational planning in recurring production, but this problematic field still needs to be studied.

In the mid 1950s systematic and very profound research was initiated in order to build and analyze mathematic scheduling models, to elaborate and use routine decision-making methods. First examples of successful research that was carried out at that time and is worth mentioning include network scheduling methods. Some interesting results were obtained in the field of queuing systems [2, 14]. At this very time the term "scheduling theory" appeared [5, 14].

Today, since industrial production in Russia is experiencing revival, there is growing interest towards scheduling problems. However, as many authors say [3, 7, 8, 14, 16, 18, 20], new real objectives in the scheduling theory have appeared and caused certain difficulties. So it is reasonable to expect a rise in relevancy of operational planning methods.

The analysis of papers dedicated to the scheduling theory lets us conclude as follows.

First, all papers can be divided into four groups:

- individual problem stating and solving in the scheduling theory;
- problem solving methods;
- applied problem solving in the conventional sector;
- new areas to apply the scheduling theory.

It has to be mentioned that publications, as a rule, address individual cases among general ones. We can make a note of the following problems: Johnson [4], Akers, Friedman, Lenstra & Reeg, Lenstra & Rinnooy Kan. In their turn, individual problems are marked off general ones in the mentioned class. For example, Bellman-Johnson problems for two machine tools, the same for three machine tools; two service problem; single route Johnson's problem; conveyer type problems.

Thus, the literature sees into a wide range of individual problems of the scheduling theory and calendar planning quite in detail. However, the aforementioned publications do not have general solutions to problems of the scheduling theory; tough problems of the scheduling theory are approached separately and indeterminate problems are mentioned.

The number of models and degree of their similarity and versatility are gradually growing and grasping a larger scope of possible applications – scheduling of production, transport, military operations, teaching, IT processes, etc. As these models are getting more and more sophisticated the same is happening to routine decision-making methods that use these models.

The following may be said about the existing problem-solving methods. The scheduling theory objective is a specific optimization problem and practically all optimization methods known today are used to solve it. The scheduling theory objectives come down to the problem of mathematic programming: linear, non-linear [18], dynamic, integral-valued, and discrete ones [19]. Network setting of a problem [2, 14], the game theory method [6] are widely used. Asymptotic methods and methods of multi-extreme problem-solving [3, 15] are studied. The combining method, the graph theory method [2, 8], in particular, the mixed graph method [8]. Methods of multi-criterion problem-solving are presented, methods of stability analysis of problem-solving in the scheduling theory [17] are considered. A great number of research papers are dedicated to approximation methods: the Monte Carlo method [13], "bottleneck" method, etc.

In connection with the above features, the planning for many domestic enterprises operating unsustainably. This situation is not satisfactory. Therefore, in our opinion, the development of new planning methods based on models that are adequate to the real conditions of production is relevant and timely.

The failure of the first attempts to automate the scheduling caused by reducing them to the decision of individual disparate tasks. The present stage is characterized by a systematic approach and a comprehensive solution of scheduling problems. This means entering scheduling system as a subsystem in a single integrated automated enterprise management system, which implies a close functional relationship with the other subsystems in the first place, with the subsystems of accounting and operational control over the course of production.

Analysis of practical application of the scheduling theory methods proves their high efficiency.

The simplest and most commonly used operational planning method is a graphic method. Charts and graphs are easy to read and allow managers to analyze production capacity utilization and improve operational plans following their gut feeling and common sense.

The Gantt chart of production capacity utilization has several major limits of use. One of them is that it does not take into account the variety of production situations, such as breakdowns or human errors, which demand to do the same job again. The chart has to be regularly updated when new works appear or time assessments are revised. The drawback of simple graphic methods is that dependences between operations are not clearly seen. It is especially noticeable when the process is complicated, sub-divided and includes a lot of operations.

This drawback of graphic methods excludes network analysis. The complex of works to be planned is reflected as a network model. It gives more opportunities to calculate time characteristics and simulate situations. At the same time the network modeling of a work complex does not allow us to see the workplace capacity charts.

Different techniques, which we use today, treat the problem of optimal values calculation of the given norms in a different way. In the context of scheduling problem-solving on big amounts of information, the 2nd, 6th and 8th techniques can be of the biggest practical interest. If these techniques, which contain different logical rules and priority functions, are used, scheduling problems can be simplified and actually solved.

Thus, the aforementioned allows us to conclude that the problem of the scheduling theory and calendar planning with the use of new methods is an important and relevant scientific problem.

II. PROBLEM FORMULATION

Today's approaches to operational scheduling of workplaces as an optimality criterion, as a rule, use various time characteristics that do not always properly reflect the dynamics of economic parameters of production.

The main scheduling problems are presented in Table 1.

Table I. Approaches to selection of the best scheduling variants

Year	Authors	Criterion
1966	J. Muth, J. Thompson, P. Winters.	Cost minimization (stocks, equipment adjustment, supply lags)
1975	Conway P.V., Maxwell, V.L., Miller, L.V.	Minimization of the beginning moments sum of final operations for all works
1979	Sokolitsyn, S.A.	V.A. Petrov's method is used as a basis: minimization of the production cycle length with the use of scheduling guidelines (priority sequence depends on whether production time of separate item batches increases or decreases).
1982, 1988	Kuzin, B.I.	Minimization of the total production cycle length with the use of priority laws and preference functions
1984	Tyutyukin V.K.	Minimization of the total production cycle length through finding successive locally optimal plans
2002	Tsarev V.V.	Minimization of planned employment variances from actual employment of workers. Minimization of production in progress

The main drawback of most scheduling models that are recommended is the use of a single criterion approach to a given problem. However, the scheduling problem is, in its own sense, a multi-purpose task: on the one hand, it is necessary to complete the production program to a full extent. On the other hand, it has to be done with maximal efficiency of production. Thus, in scheduling, costs related to allocation and completion of orders can change and the profit share that the workshop obtains can vary due to different scopes of work or as a result of dynamics in the used time resources. Therefore, when choosing an index of production in progress as an optimality criterion for operational scheduling of workplaces, working assets of an enterprise are consciously and evidently understated, because scheduled work results in longer production cycle which is a major factor affecting the size of production in progress. According to the research of authors, when a workshop operates in accordance with the elaborated schedule, the size of production in progress is 1.5-2.0 times bigger in comparison to the value that is used to calculate rated working assets. If this condition is not considered, the value of rated working assets will be understated and, as a result, the production program of an enterprise may fail.

Moreover, results of the research have shown that the production plan cannot always be fully completed in the current planning horizon if the former one has been elaborated based on the common model with restrictions of resource facilities. Hence, the equipment gets less used in comparison to the normative level and there is a drop in stock at the supply warehouse with simultaneous increase in the stock at the finished products warehouse due to the line of goods made to cooperation.

In recurring production it is economically important to manufacture the order in bigger batches. If the batch size of parts put into production grows, less time is needed to readjust the equipment, the fund of fieldwork per shift increases, labor productivity and quality of produced goods improve. Furthermore, less amounts of materials are consumed and less working time is spent to manufacture additional samples that are used for customization technological purposes, for example, quality control of blanking operations.

Economic performance of a company also improves because of steadier output and more regular work of production divisions. Regular operation of workshops and sections is reached through more accurate planning of demand for production capacities and a more balanced utilization of separate groups of equipment and workplaces during a planning horizon. Utilization is usually balanced through changing calendar dates of goods production and transferring production of separate lines of goods between divisions.

With less overtime work and lost hours due to organizational reasons, cost of manufactured goods goes down and their quality improves.

Thus, operational planning of production in the existing market conditions is a useful tool to improve efficiency of in-house planning as a whole. Enhanced operational planning helps to obtain a positive financial result from company's activities, brings additional profits and improves profitability.

So, it is reasonable to develop such an optimization model that would be based on implementing a multi-purpose approach and consider the essential features of schedules. More appropriate optimality criteria of the scheduling problem, in our opinion, include maximization of production profitability and compliance with the scope and line of good of the production plan by means of internal resources of a workshop.

One of possible types of economic and mathematical scheduling models for machine shops can be an optimization model that uses a multi-criterion approach and is one of the structural elements in the operational production management scheme.

III. PROBLEM SOLVING

Let there be a machine shop (with subject or technological specialization) that has a certain number of machines, including doubling machines. Technological operations for production of batches of parts on the corresponding machines within a given time period have to be organized in such a way that parts are produced and delivered within certain deadlines. Technological routes for parts to pass machines are different. Each separate batch of parts is characterized with preparation time standard whereas each part is defined by the content and sequence of technological operations and standards of floor-to-floor time. Operation of workplaces of the machine shop has to be scheduled in such a way that a number of major requirements are met and certain objectives are reached, being represented as optimality criteria.

Most important requirements to be considered in the optimization model are the following:

- each machine can do no more than one part-operation;
- before parts have been processed in the previous operation of the technological process, beginning of their processing in the following operation cannot be planned;
- the same process operation to manufacture a part can be planned for any doubling machine that is off-duty;
- process of part-operation manufacturing on a machine cannot be interrupted;
- workplaces are loaded within the limits of the normative time reserve.

In the scheduling problem, beginning and end time of technological process operations is unknown for certain machines and different batches of time.

The analyzed literary sources have brought us to a conclusion that various criteria and algorithms are used in operational scheduling of machine sections workplaces whereas multi-criterion approach is mainly used in scheduling tasks. The economic and mathematical scheduling model of workplaces operation for subject and technological sections of machine shops that is proposed here includes two optimality criteria: percent completion of the production plan by means of the internal resources of a workshop and production profitability.

The scheduling problem can be presented in the following way [10, 11]. It is necessary to choose such a variant of the standard-plan (schedule) of workplaces operation of a machine shop that

$$P(\mu_m^*) \to \max,\ \mu_m^* \in M_{\text{вп}}\ ; \quad (1)$$

$$R(\mu_m^*) \to \max,\ \mu_m^* \in M_{\text{вп}}\ ; \quad (2)$$

$$0 < R(\mu_m^*) \le R_{\text{и}}\ ; \quad (3)$$

$$0 < P(\mu_m^*) \le 100\ ; \quad (4)$$

$$M_{\text{вп}} = \{\mu_m : 1 \le \mu_m \le K_{\text{вп}}\}; \quad (5)$$

$$K_{\text{вп}} = (\pi!)^q, \quad (6)$$

where

μ_m − number of the schedule variant of workplaces operation of the workshop for m iteration of calendar scheduling;

μ_m^* − number of the best schedule variant for workplaces operation for m iteration of its development;

$M_{\text{вп}}$ − manifold of principally possible variants of schedules for workplaces operation;

$K_{\text{вп}}$ − total number of principally possible variants of schedules for workplaces operation;

π – total number of batches of parts (orders) that represent the line of goods in the production plan of the workshop;

q – number of pieces of production equipment in the workshop;

R − production profitability if the workshop operates by μ_m variant of schedules that reflects efficiency of workshop's contribution into the net profit value of the company in relation to the share of the company capital (fixed and working one) allocated to the workshop for operational management, %;

$R_{\text{и}}$ − production profitability mediated by the line of goods and scope of the production plan set for the workshop, established prices and structure of production prime costs, amount of fixed production assets of the workshop and working assets that depend on the accepted batching of products, %;

P − percent completion of the production plan by means of the workshop's internal resources if it operates in accordance with μ_m variant of the schedule.

Objective function (1) reflects the condition for search of such a variant of the schedule that would result in the biggest percentage of the workshop production plan implemented with the use of internal resources of the workshop.

Objective function (2) contributes to finding such a variant of the schedule that would provide maximal production profitability.

Restriction (3) allows considering only those variants of the schedule that would make it possible to get a positive production profitability value and would not exceed the value that the workshop could get if it operated in ideal conditions.

Restriction (4) reflects the need for complete or partial implementation of the workshop production plan by means of internal resources of the workshop.

Formulae 5 and 6 reflect the manifold and number of possible variants of the schedule at the set qualities of batches of parts (orders) – π and number of pieces of technological equipment – q.

Practical experience shows that it takes a lot of time to elaborate one variant of the schedule if no computer is used. Thus, to develop one variant of the part-operation schedule for a large machine-tool section, which produces 120 or more types of parts per year, about 20 man-months are needed [20]. Such a big time consumption and need for schedules to operate efficiently justify application of modern personal computers to elaborate schedules for sections and workshops, which considerably diminish labor intensity of scheduling. Thus, it takes 1-4 hours for a computer to elaborate one variant of a part-operation schedule, depending on the dimension of the problem and complexity of the calculation system, which are conditioned by the optimization model applied and mathematic method of its implementation [20].

The two-criterion model elaborated for scheduling of a machine shop calls for lots of input business, economic and technological parameters to be implemented, which are not always available to the full extent for an operating enterprise [11, 21]. This drawback can be eliminated with a more compact economic and statistical scheduling model for a machine shop. It just needs few technological and organizational parameters, such as operational technological routes, norms of floor-to-floor time by operations, structure of the technological equipment park, line of goods and scope of the production plan, time reserves, workplace capacity with one type of technological operation (work) within one month and some others [8, 10].

Study of cause and effect relations between indices of profitability, recurring production level, equipment utilization and others has allowed finding the factors with the biggest impact on production profitability variation.

This statistical study of economic processes at an enterprise has revealed connection between the phenomena that are reviewed, its qualitative assessment and analytical expression.

In our opinion, change of the effective condition or criterion index of the economic and mathematical model – production profitability is conditioned by change of such factors as coefficient of workplace capacity with one type of work within one month, an average size of a labor subject batch, capacity efficient of technological equipment or standard calculated floor-to-floor time. As a result, the only economic parameter of the model is production profitability in the form of functional dependence on the coefficient of workplace capacity with one technological operation (work) within one month.

Expressions of the economic and statistical model (7), (9), (10), (11) do not require clarifying since they have not been reviewed in the economic and mathematical model.

The expression of the economic and statistical model (8) is analogous to the expression of the economic and mathematical model (2), the only difference being the fact that the production profitability value, which is obtained in a statistical way and which represents a functional dependence, is used in its restrictions.

IV. Conclusion

At the heart of all the methods for calendar scheduling jobs enterprise traffic regulations are made. The most common are:

- the size of the shipments of parts and assembly units;
- duration of the production cycle of manufacturing batches, parts and assembly units;
- craft backlogs (cyclic, technology, assets, insurance).

They determine the economically justified in ordering blanks, assembly units in time and space to process transactions processing and assembly. Existing at the time of different methods in different ways solve the problem of finding the optimal values of these regulations.

From the point of view of solving operational scheduling on large amounts of information, the greatest practical interest are Gantt charts, based on the construction of which is necessary simulations and rules of precedence. Using these techniques, containing a variety of logical rules and priority function, we can simplify and solve the real problems of drawing calendar schedules.

The essence of one of the algorithms for constructing the timetable that may be proposed, consists of three stages and is as follows.

At the first stage the sequence of any given order (manufacturing batches of objects). It is provided only when the control is localized to the horizon of five to seven days. Blocking of the first stage is carried out when the calendar Timetable jobs mechanical areas of the shop is for the control horizon equal to one month.

In the second phase, the consolidation of the positions of the nomenclature of industrial application running in production in this horizon control for specific jobs.

In the third stage the production of a calendar schedule batches of objects in which the selected control horizon is reached minimum value cycle time under the following restrictions:

- Prevention of manufacturing at one workplace in the same time interval of two different lot numbers of subjects;
- Preventing the shift to the left, followed by the start of the operation to complete a batch of items compared with the end of the previous operation.

At the end of the third stage is a viable option timetable of the mechanical workshop.

Theoretical and methodological basis of the research relies on papers of Russian and foreign scientists on mathematic and instrument economic methods of scheduling for machine shops of mechanical engineering enterprises. Problems have been solved through principles of comprehensive approach, theory of sets, economic and mathematical modeling, including simulation modeling, statistical and logical analysis.

Thus, the research results have allowed the author to propose a new two-criterion approach to finding an acceptable scheduling option for workplaces of machine sections that would consider both demand for goods of the enterprise and production profitability. This approach has been used to develop an optimization two-criterion economic and mechanical model and one-criterion economic and statistical model of operational scheduling for machine shop sections.

The optimization model that has been developed is based on implementation of multipurpose approach and considers the essential feature of operational scheduling for workplaces. The model uses two optimality criteria: maximization of production profitability and implementation of the production plan by means of the internal resources of a workshop.

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