Approaches to Enhancing Efficiency of Production Management on Shop Floor Level

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Abstract: The paper presents several approaches to enhancing efficiency of management of multiproduct single-unit and small-batch discrete production on shop-floor level, namely optimization during job scheduling, prediction of schedule execution, and support of decision-making during assignment of activity executor. For every approach, problem statement and example, potential method of solution and benefits of the shop floor level from using these approaches are given.

1 INTRODUCTION

Enhancing efficiency of production management on shop floor level using information technology can be implemented through a number of approaches:

1. Use of precise and heuristic algorithms of optimization during job scheduling;
2. Assessment and prediction of schedule execution based on statistical data;
3. Support of decision-making during assignment of executor based on empirical data extraction using Data Mining technology.

A large number of research efforts have been dedicated to the problem of job scheduling, suggesting new and new variations of well-known algorithms and heuristics as the solution (Boussaïd et al., 2013, Abazari et al., 2012, Xi and Jang, 2012, Lei and Guo, 2014, Huang, 2013). The second problem relates to risk assessment, however, it has not been found by the authors in publications in such statement. Knowing the execution uncertainty can be useful even if the first problem is resolved successfully. The third type of problems is presented in publications mostly in relation to assembly operations (the assembly line worker assignment and balancing problem), i.e. applicable to large-batch and mass production with criterion of cost minimization or production cycle minimization (maximum pace of production). To resolve these problems taking into account the specifics, the same algorithms are used that for the first problem of shop floor scheduling (Borba and Ritt, 2014, Mutlu et al., 2013). Such solutions are not adequate for single-unit or small-batch production.

Let us consider each of the approaches and benefits of their implementation in more detail.

2 BALANCED LOAD OF PRODUCTION FACILITIES

Efficiency of a company with multiproduct single-unit and small-batch discrete production has a direct relation to not only the capacity of the shops and sectors, but also the proper organization of production startup. The more balanced the shops are loaded, the fewer situations will occur, when one shop is in a standstill, and the other becomes a bottleneck due to overload at the same time. Such situation is typical for tool shops and shops with customized equipment that provide for the process engineering and are responsible for single-unit or small-batch production of specific auxiliaries and custom equipment.

Many advanced information systems of shop floor level (MES) allow scheduling production on a minute-scale (e.g. PolyPlan, FOBOS, HYDRA). However, under continuous update of schedule and appearance of urgent high-priority jobs, such schedule quickly becomes invalid. This is especially true for multiproduct single-unit and small-batch production, where almost all operations are

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performed on one and the same universal equipment, and norms for these operations have significant uncertainties (Levi, 2011). In this situation, balancing the load of shops and sectors in short- and medium-term will be more effective than scheduling production on a minute-scale.

2.1 Problem Statement

Let $\mathbb{U}$ – multitude of shop sectors, $u \in \mathbb{U} = \{u_1, \dots, u_{U_o}\}$, $|\mathbb{U}| = U_0$;

d_S – start date of scheduling period; d_F – end date of scheduling period;

$\mathbb{D}([d_S;d_F])$ – multitude of workdays in the period $[d_S;d_F]$, $d \in \mathbb{D}([d_S;d_F]) = \{d_1, .., d_{D_{sf}}\}$, $|\mathbb{D}([d_S;d_F])| = D_{SF}$;

$\mathbb{W}([d_S;d_F])$ - multitude of all scheduled production jobs with deadline within the scheduled period $[d_S;d_F]$, $w \in \mathbb{W}([d_S;d_F]) = \{1, \dots, W_{SF}\}$, $|\mathbb{W}([d_S;d_F])| = W_{SF}$;

$\mathbb{A} = (\mathbb{W}, \mathbb{D})$ - multitude of execution options of scheduled jobs per workdays, $a \in \mathbb{A} = \{a_1, \dots, a_{A_o}\}$, $|\mathbb{A}| = A_0$;

Let us denote the target function for resolving the problem of balanced load via f_{obj}, [h], then the statement of combinatorial optimization problem looks as follows: need to determine

$$a^* \in \mathbb{A}: f_{obj}(a^*) = \min_{a \in \mathbb{A}} (f_{obj}(a)) \qquad (1)$$

The specific appearance of the target function can be different depending on what parameters of load schedule are considered significant.

2.2 Analysis of Potential Target Functions

The following characteristics were reviewed as the major ones for the target functions:

- Account for absolute overloads;
- Account for relative overloads;
- Account for peak overloads;
- Account for absolute underloads;
- Account for relative underloads;
- Account for peak underloads;
- Account for distinction of kind of overloads and underloads.

Table 1: Comparison of potential target functions.

No.	Characteristics f_{obj}	Account for overloads			Account for underloads			Account for distinction of kind of overloads & underloads
		Absol.	Relat.	Peak	Absol.	Relat.	Peak	
1	$\sum_u \Delta_u$	+	–	–	–	–	–	–
2	$\sum_u \sum_d \begin{cases} (Z_d^u - \bar{Z}_{max}^u)^2, Z_d^u > \bar{Z}_{max}^u \\ 0, Z_d^u \le \bar{Z}_{max}^u \end{cases}$	+	–	+	–	–	–	–
3	$\sum_u \sum_d \lvert Z_d^u - \bar{Z}_{max}^u \rvert$	+	–	–	+	–	–	–
4	$\sum_u \sum_d (Z_d^u - \bar{Z}_{max}^u)^2$	+	–	+	+	–	+	–
5	$\sum_u \sum_d {Z_d^u}^2$	–	–	+	–	–	–	–
6	$\sum_u \sum_d \begin{cases} (Z_d^u - \bar{Z}_{max}^u)^2, Z_d^u > \bar{Z}_{max}^u \\ \lvert Z_d^u - \bar{Z}_{max}^u \rvert, Z_d^u \le \bar{Z}_{max}^u \end{cases}$	+	–	+	+	–	–	+
7	$\sum_u \max_d Z_d^u$	–	–	+	–	–	–	–
8	$\sum_u \max_d \lvert Z_d^u - \bar{Z}_{max}^u \rvert$	+	–	+	+	–	+	–
9	$\max_u \max_d L_d^u$	–	+	+	–	–	–	–
10	$\max_u \max_d \delta_d^u$	–	+	+	–	–	–	–
11	$\sum_u \sum_d \begin{cases} c_u(Z_d^u - \bar{Z}_{max}^u), Z_d^u > \bar{Z}_{max}^u \\ c'_u(\bar{Z}_{max}^u - Z_d^u), Z_d^u \le \bar{Z}_{max}^u \end{cases}$	+	–	–	+	–	–	+

Table 1 summarizes the information on these characteristics for several potential target functions (Abazari et al., 2012). In the majority of research, the time functions are used as target, such as maximum production period, maximum delay, overall delay, etc. (Zhang et al., 2013) that are minimized similarly (1).

In the functions in the Table:

Δ_u- total overload at sector u per all scheduled jobs for all workdays, [h], calculated as per expression (2):

$$\Delta_u = \sum_d max\begin{pmatrix} Z_d^u - \bar{Z}_{max}^u \\ 0 \end{pmatrix} = = \sum_d \begin{cases} Z_d^u - \bar{Z}_{max}^u, \text{if } Z_d^u > \bar{Z}_{max}^u \\ 0, \text{if } Z_d^u \leq \bar{Z}_{max}^u \end{cases} \quad (2)$$

Z_d^u- total load of sector u per all scheduled jobs for workday d, [h], calculated as per expression (3):

$$Z_d^u = \sum_w z_{uwd} \quad (3)$$

z_{uwd}- load of sector u with scheduled job w for workday d, [h];

$\bar{Z}_{max}^u$ – maximum capacity of sector u for a workday, [h];

L_d^u – relative load of sector u for day d calculated as per expression (4):

$$L_d^u = \frac{Z_d^u}{\bar{Z}_{max}^u} 100\% \quad (4)$$

δ_d^u – relative overload of sector u for day d calculated as per expression (5):

$$\delta_d^u = \begin{cases} \dfrac{Z_d^u - \bar{Z}_{max}^u}{\bar{Z}_{max}^u} 100\% \text{ if } Z_d^u > \bar{Z}_{max}^u \\ 0, \text{if } Z_d^u \leq \bar{Z}_{max}^u \end{cases} \quad (5)$$

c_u – overload accounting coefficient on sector u (cost of extra time equipment operation);

c'_u – underload accounting coefficient on sector u (cost of equipment standstill).

2.3 Example

Let us review the schedule of tool shop of one of the enterprises within the complex of State Corporation ROSATOM. It uses quarterly scheduling of auxiliaries production, so this period should be used (about 90 day, 65 workdays) to obtain a balanced schedule. For a quarter, they execute about 800 scheduled jobs, one tenth of which is not defined beforehand and emerges as the result of current operations of process engineering. As a rule, such jobs are urgent and have high-priority, resulting in update of schedule of other jobs. One can avoid update in case of perfect balancing of load for all sectors or at least for bottlenecks. For a tool shop, availability of only one jig boring machine is a bottleneck. Maximum number of execution options for the aforesaid schedule equals to the number of deployments with repetitions out of n=D_{SF} days on k=W_{SF} scheduled jobs, which equals to ${D_{SF}}^{W_{SF}} = 65^{720} \sim 10^{1305}$. The problem is considered transcomputational (computed for unacceptably large time) already at the cardinality of a set of search 10^{93}.

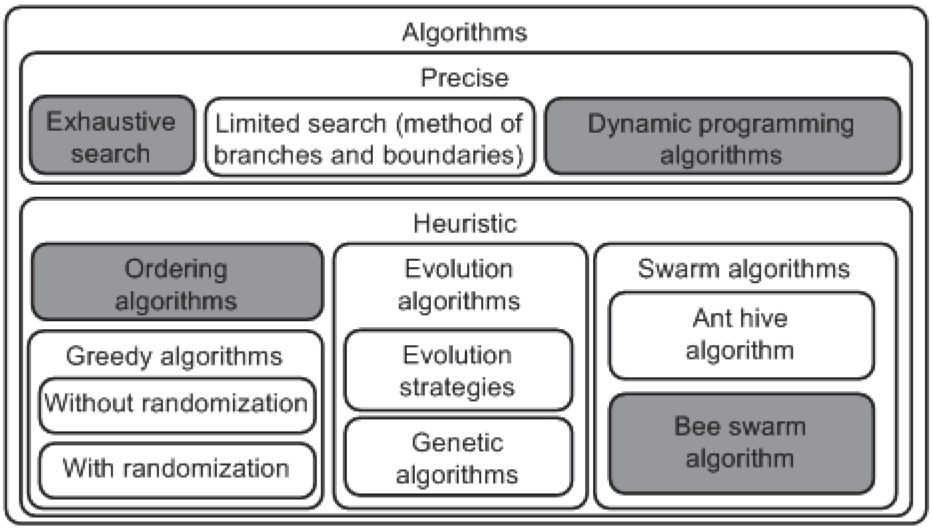

Figure 1: Considered algorithms.

2.4 Methods of Solution

The stated problem of combinatorial optimization is solved in the area of discrete programming. Since the problem is transcomputational, finding the global optimal solution is possible only using limited search. Pseudo-optimal solution can be obtained using various algorithms found in Figure 1 (Reingold et al., 1980, Conway et al., 1975, Spears, 2000, Kennedy and Eberhart, 1995, Mullen et al., 2009, Fister et al., 2013). Highlighted in grey in the Figure are the algorithms unsuited for solving the stated problem for different reasons.

2.5 Benefits

Balancing the load of shop sectors will help to use the shop capacity to the fullest at each moment of time and reduce the number of updates of production schedule by organizing their timely startup.

3 ASSESSMENT AND PREDICTION OF SHEDULE EXECUTION

Another approach is assessment and prediction of schedule execution based on statistical information. Such information can be accumulated in the operative dispatching system or in the corporate MES.

3.1 Problem Statement

This problem has two components – primal and inverse.

Primal problem. Let there is a schedule out of k jobs. Need to determine probability of each scheduled job execution and probability of the whole schedule execution.

Inverse problem. Let the probability of the whole schedule execution P^* is stated. Need to determine probability and timeframe of each scheduled job execution, which together satisfy the stated value of the whole schedule execution probability.

3.2 Example

A shop manager always tries to execute the medium-

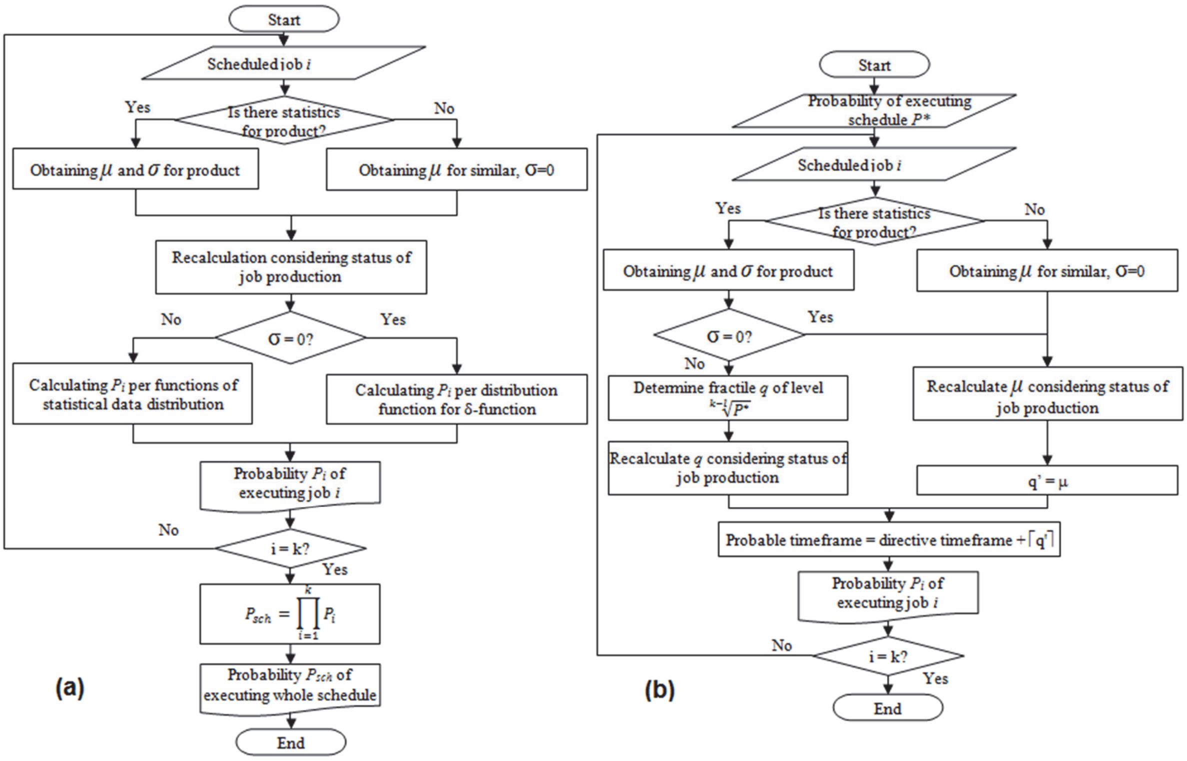

Figure 2: Algorithms (left) of assessment and (right) prediction of schedule execution.

term schedule at least by 90%, if not by 100%. Let there is a need to execute the schedule of tool shop with 90% probability without updating timeframe. It is known that deviations between the directive and realistic schedule of ring gauge production, reduced by the amount, obey trapezoidal distribution with a certain mean and rms deviation. The shop planners need to determine the date of gauge production startup.

3.3 Methods of Solution

Flow charts of algorithms for solving primal and inverse problems are found in Figure 2. Statistics concerning deviations between scheduled and realistic production dates of the same or similar products is the source information. The distribution law that these deviations obey should be determined in advance. (Kobzar, 2006)

3.4 Benefits

Such assessment will allow the managers and shop planners to make timely decisions on the priority of this or that scheduled job and intensify production, as well as on possible change of production startup date compared to the calculated one considering predicted deviations.

4 SUPPORT OF DECISION-MAKING DURING ASSIGNMENT OF EXECUTOR

Another approach to enhancing efficiency of production management on shop floor level is support of decision-making for job foremen during assignment of executor, which can be based on empirical data extraction using Data Mining technology.

4.1 Problem Statement

Let the source information on job is stated: type of operation, type of product, grade of operation, time allowance, number of operations. The most suitable executors for this job should be determined.

4.2 Example

Let the turner job foreman has to assign turning machining of two ring gauges to a worker. The operation is for a 6th grade turner and has a respective time allowance. There are 20 turners on the staff, and the foreman should choose between them. When making a choice, he needs to consider, if any of the workers has had experience of machining ring gauges recently to minimize the probability of defect, since the gauges are already urgently demanded by the customers at the primary shops and there is no time to restart the production of auxiliaries. Besides, the scheduled load of suitable executors has to be considered to eliminate disruption of other jobs. According to the classification per area of application (Wong and Lai, 2011), this assignment problem can be related to both 'distribution' and 'quality control'.

4.3 Method of Solution

This problem can be solved using neural network performing classification of jobs per executors. For each type of operation, there should be its own neural network. Solution chart is found in Figure 3. The choice of network architecture and method of training are the issues for another dedicated research and are detailed in (Haykin, 2006, Graupe, 2007).

4.4 Benefits

This mechanism can ensure the job foreman makes a more justified decision to assign the most experienced and qualified executor to perform a job considering the current situation in the shop.

5 CONCLUSIONS

This paper presents approaches to enhancing

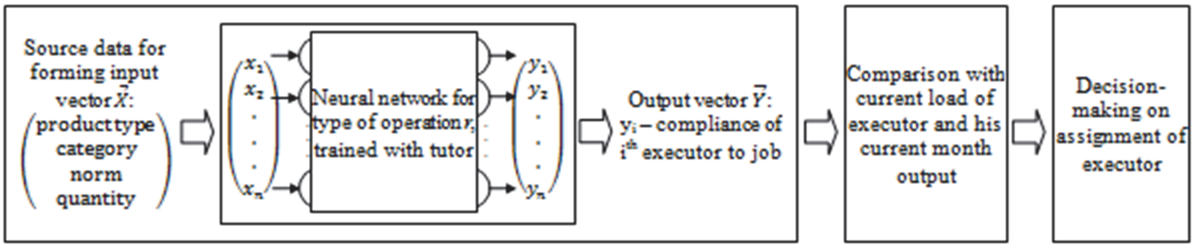

Figure 3: Assignment of job executor.

efficiency of production management on shop floor level implemented merely by software.

Analysis of potential target functions and possible algorithms for solving the problem are presented for the stated problem of balanced load of production facilities. Other two approaches are based on historical information accumulated in the industrial base. Statement of primal and inverse problems of assessment and prediction of shop schedule is presented, as well as flow charts of their solution. Statement and solution chart of problem of decision-making support during assignment of executor is also given. Benefits for shop floor staff in their routine operations are identified for all the approaches.

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