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CREATING ROBUST SCHEDULES BASED ON PREVIOUS PRODUCTION PROCESSES

The development of competitiveness at world markets caused the need to increase the production flexibility. An essential tool in achieving this could be production scheduling. However, in this process there are a lot of complex optimization problems. The paper presents the idea of production scheduling. First of all, typical scheduling problems and methods of solving them are described. Moreover, the issues of creating robust schedules are presented. In the final part of the paper the author offers a concept of creating predictive schedules based on the analysis of previous production process.

Keywords: *production scheduling; job-shop problem; robust schedule; predictive production scheduling.*

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СКЛАДАННЯ ТОЧНИХ ГРАФІКІВ НА ПІДСТАВІ АНАЛІЗУ ПОПЕРЕДНІХ ПРОЦЕСІВ ВИРОБНИЦТВА

У статті показано, що розвиток конкурентоспроможності на світових ринках спричинив потребу у збільшенні гнучкості продукції і своєчасності реалізації виробничих замовлень. Важливим інструментом у досягненні цієї мети може стати відповідне планування виробничих завдань. Проте, даний процес пов'язаний з низкою складних задач оптимізації. Представлено процес планування виробництва, типові проблеми систематизації виробничих завдань, а також методи їх розв'язання. Крім того, продемонстровано ідею складання точних графіків, а також концепцію побудови прогнозованих графіків на підставі аналізу попереднього перебігу виробничого процесу.

Ключові слова: *планування виробництва; проблема job-shop; стійкий графік; прогнозоване планування виробництва.*

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ПОСТРОЕНИЕ ЧЕТКИХ ГРАФИКОВ НА ОСНОВЕ АНАЛИЗА ПРЕДЫДУЩЕГО ХОДА ПРОИЗВОДСТВА

В статье показано, что развитие конкурентоспособности на мировых рынках вызвало необходимость увеличения гибкости производства и своевременности реализации производственных заказов. Необходимым инструментом для достижения этой цели может стать соответствующее планирование производственных задач. Однако с этим процессом связан ряд сложных оптимизационных проблем. Представлены процесс планирования производства, типичные проблемы планирования производственных задач, а также методы их решения. Кроме того, предложена идея построения четких графиков, а также концепция создания прогнозированных графиков на основе анализа предыдущего хода производства.

Ключевые слова: *планирование производства; проблема job-shop; четкий график; предсказывающее планирование производства.*

Problem statement. The development of competitiveness at world markets has caused the need to increase production flexibility. Moreover, there is a need for pro-

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duction optimization. Nowadays it is not enough to produce a lot of a unified products. Production enterprises have to realize customers' needs (Palajova et al., 2011). An essential tool in achieving this purpose could be production scheduling. However, in this process there are a lot of complex optimization problems, also associated with profitability of production (Gola et al., 2013).

In the scheduling process, there is a number of problems that are divided into several categories (Muhammad Shahrizal et al., 2011). The most often analyzed in literature is the job-shop problem (called a general job-shop problem). The job-shop case involves the complete ordering of tasks arising from technological limitations and its occurence in production cells. Therefore, job-shop problem is associated with real production systems. Job-shop is an NP-hard problem. This means that finding the optimal solution is very difficult. Moreover, job-shop problem is a typical theoretical problem and there are a lot of simplifying principles (compliance or non-compliance with reality) (Wojakowski, 2012). Therefore, this issue is the subject of research.

Literature review. Production scheduling is the subject of many publications. J. Herrmann gives a historical overview of the issue – starting from the first methods of production planning until contemporary solutions (Herrmann, 2006). Currently the most frequently analyzed issue of scheduling is a job-shop problem. This issue is considered in many ways. The main subject is the optimization of the job-shop problem (Golenko-Ginzburg et al., 2002). Different authors propose various approaches to this issue. A hybrid genetic algorithm (Park et al., 2003), a tabu search algorithm (Hurink et al., 2002) and a variable neighborhood search for job-shop scheduling are used (Roshanaei et al., 2009). Moreover, literature discusses the issues of flexible job-shop problem and robust scheduling problems (Al-Hinai et al., 2011). Robust scheduling is a very interesting issue, because a solution to this problem helps implement robust schedules in real production systems (Yan et al., 2012). There are several methods to solve this problem (Escamilla et al., 2012), but still this issue is the subject of many studies.

Importance of production scheduling. The term "production scheduling" means determining the size of production batches and creating a detailed schedule (taking into account all limitations). The aim of scheduling is the best use of enterprises resources and thereby competitiveness increase. The result of scheduling is developing a schedule of individual tasks (in the form of a chart or a description) (Pajak, 2006). The most commonly used chart in the production scheduling is the Gantt chart (Figure 1).

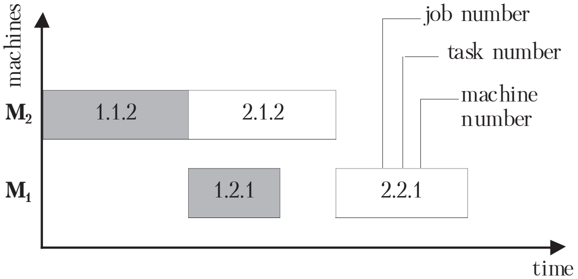

Figure 1. **Example of a schedule**

During the a schedule design appropriate criteria are defined and used. The most commonly used criteria are: the criterion of minimizing the length of a cycle, the criterion of minimal downtime, the criterion of minimal deviation of completion date. Moreover, the rules of priorities are also employed. In literature there are about 100 such rules – e.g.: "first in – first on" rule, the shortest (the longest) time an operation rule, the longest time the next operation rule, the longest queue rule (Knosala, 2002). It helps to achieve the company targets. The main target of enterprise is achieving the biggest profit at lowest manufacturing costs.

There are two basic production scheduling methods (Pajak, 2006):

- forward scheduling – time of tasks and commencement date of production are known and then the completion date of the order is determined,
- backward scheduling – time of tasks and completion date of the order are known and then the commencement date of production is determined.

Although the presented scheduling methods seem very easy, production scheduling in real production system is very difficult. It is caused by many factors which hinder this process – e.g. a great number of jobs, restrictions associated with tasks and machines, random events causing the disruptions of production.

There are several problems related to scheduling. Production scheduling problems are divided as follows (Pawlak, 1999):

- In terms of the kind of problem we distinguish: flow-shop, job-shop and open-shop problem. This kind of problems arises from the characteristics of a production system.
- In terms of randomness we distinguish deterministic and stochastic problems. They occur when a randomness factor appears in the production process.
- In terms of changes we distinguish dynamic and static problems. They depend on the variability of manufacturing process and the occurrence of tasks unknown at the time of scheduling.
- In terms of relation to practice we distinguish practical and theoretical problems. They result from various simplifications used in testing and analysis of research.

In response to production scheduling problems, there are various scheduling methods. Production scheduling methods are generally divided into optimization and approximation methods, but more particularly we distinguish (Pawlak, 1999):

- the accurate method of seeking solutions to problems;
- the method of division and limitations;
- expert systems;
- heuristic method;
- evolutionary algorithms.

Despite the existence of several methods there is still a need to develop new solutions of production scheduling problems and creating more optimal schedules (Sobaszek et al., 2013).

General job-shop problem. The job-shop problem often analyzed in literature, sometimes is called the general job-shop problem. Over the years a significantly increasing interest to this issue is observed (Wojakowski, 2012) (Figure 2).

The job-shop case involves the complete ordering of tasks arising from technological limitations. Analyzing this problem we operate on 3 sets (a set of machines, a set of tasks and a set of operations) and define the relationship between them. The job-shop problem also takes into account the following assumptions:

- each machine can perform only one operation at a time;
- you can not realize more than one operation of the task;
- operation cannot be interrupted.

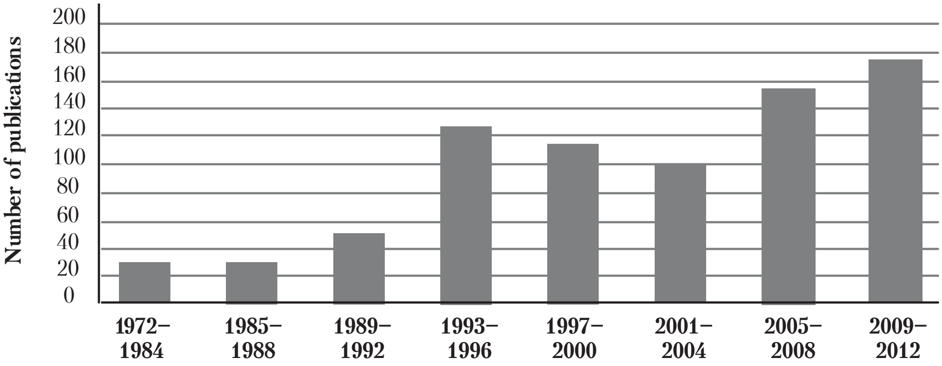

Figure 2. **Number of publication on the job-shop problem over the years**

Problems in creating production schedules also result from the fact that they belong to the class of NP-hard problems (Jensen, 2003). That means the great difficulty in finding the exact solution – very long time necessary for the algorithm implementation. To illustrate the complexity of the general job-shop problem, let's consider a simple example (Figure 3).

Example. It is assumed that in a production process should be performed 5 production tasks. Each task should be done in 2 operations by means of 2 machines.

The number of operations to be scheduled: 5 x 2 x 2 = 20
The number of all possible permutations: $20! = 2 \times 10^{18}$

Figure 3. **Example of complexity of the problem**

As we can see in the example, there are many possible permutations. In addition, finding the optimal solution among so many is very troublesome.

Detailed analysis of the general problem of scheduling shows its high complexity, and therefore it has become the subject for numerous studies. These studies are often theoretical, thus also the job-shop problem is a typical theoretical problem (Pawlak, 1999). There are a lot of simplifying principles (compliance or non-compliance with reality), that is a typical feature of test problems. The following simplifying principles are used:

1. Tasks of one job can not be executed in parallel.
2. A machine can not perform two tasks in parallel.
3. Each job has m operations (tasks) – one for each machine.
4. Each job must be done to the end.
5. Execution time of tasks is independent of the schedule.
6. Waiting of the parts for the release of the machine is permitted.
7. There is only one machine of each type.
8. A period may occur in which machines are unused.

9. The machine cannot execute more than one task at the same time.

10. Machines never break down and are available throughout the execution time.

11. Technological constraints are known in advance and unchanging.

12. There is no randomness factor.

The presented principles pose a serious limitation to the use of the proposed solutions in practice. Therefore, in recent years there appeared several scientific trends trying to eliminate the general job-shop problem restrictions. An example is the issue of flexible job-shop, which assumes the existence of a set of several machines enabling the execution of the process on alternative machines. The other example is robust scheduling, which tries to eliminate the submission related to the failure rate of machines in production and the occurrence of random factors.

Robust scheduling of production. The planning of production assumes a static process, but usually in the production process various disturbances appear (Swic et al., 2011). Among many changing factors we can distinguish: breakdowns of machines and robots, interferences associated with orders, interferences associated with tasks, incorrect estimate of the time of tasks, shortening or lengthening the time of tasks.

It is very important to prevent disturbances occurring in production process. The more changes are in the process, the greater is its disorganization. Henry Gantt, the creator of the charts used in scheduling, used to say that "the most elegant schedules created by planning offices are useless if they ignore the situation that is observed" (Herrmann, 2006). Therefore, in literature there is an issue of creating *robust schedules*.

Robust scheduling is a part of the process called predictive-reactive scheduling. In this approach there are two stages (Klimek et al., 2008):

- predictive scheduling (associated with the planning stage);
- reactive scheduling (associated with the implementation stage).

Robust schedule is created during the first stage together with a nominal schedule (taking into account the production process parameters). At the reactive stage schedule is created during production. Therefore, any change in production processes results in the formation of an alternative schedule.

The purpose of robust scheduling is minimizing the impact of various disturbances on the implemented process. Created schedule will be not susceptible to disruptions appearing in production processes. Most commonly used techniques of schedules immunization are (Klimek et al., 2008):

- redundancy techniques;
- conditional scheduling;
- building partially ordered schedules;
- sensitivity analysis.

Robust schedules can improve production processes. A well-made robust schedule is better than modification of existing schedule, which often requires a large number of complex calculations.

Production scheduling based on previous production processes. Production process disturbances adversely affect the functioning of production enterprises. An example is the failure to realize orders on time. A company cannot afford having this situation because it will lose customers. Especially breakdowns of machines and changes in the times of tasks are the most dangerous disturbances. Therefore, using available tools and methods, we propose the concept of robust scheduling, presented in 4 stages (Figure 4).

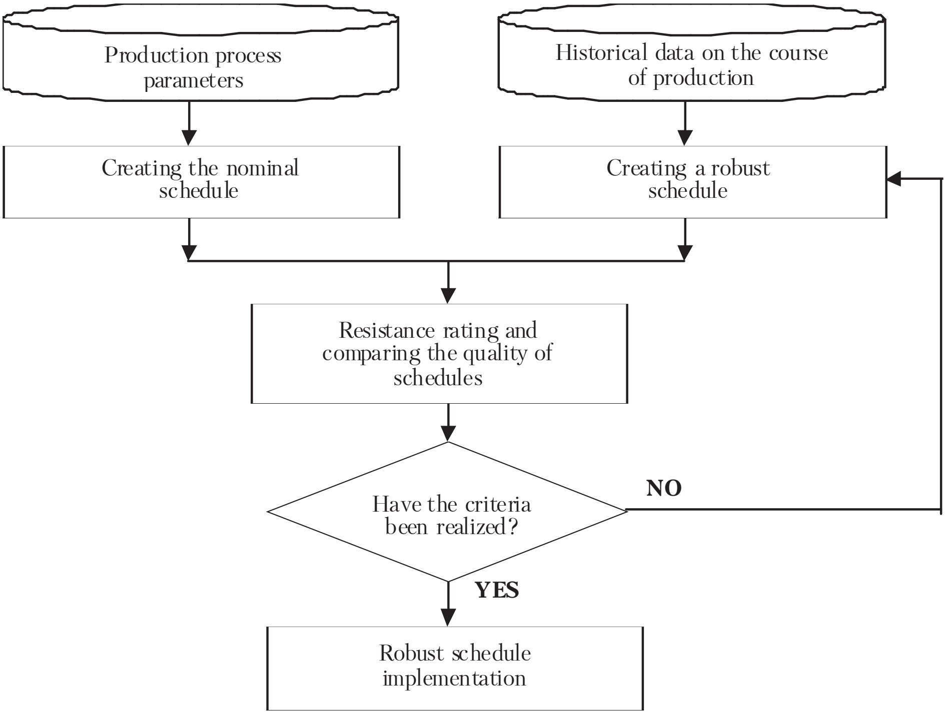

Figure 4. **Block diagram of the considered concept,** *authors*

Stage 1. Production process data analysis (the number of tasks, duration of tasks, available machines) and creating the nominal production schedule. To create a schedule appropriate methods of scheduling can be used. For this purpose LiSA software can be used – computer program which helps creating schedules by mean of exact or heuristic algorithms. LiSA is the abbreviation for "A Library of Scheduling Algorithms".

Stage 2. The use of historical data of the process to determine machines that could be damaged and tasks the execution time of which may change. For this purpose we can use the tool used to anticipating and predicting events – e.g. statistical analysis or artificial neural networks.

Stage 3. Creating a robust schedule with time buffers. Schedule will be created by adding time buffers in vulnerable areas of schedule – the application will find the technique of redundancy.

Stage 4. The last stage of the presented concept is the robust schedule rating and comparing the quality of nominal schedule with robust schedule. In case of achieving the stated purpose robust schedule will be implemented. In case the stated purpose is not achieved – rescheduling by means of other algorithm or detailed analysis of the parameters of the considered disturbances should be performed.

Conclusions and further studies prospects. Production processes are very dynamic and exposed to unpredictable situations. Creating schedules taking into account the production process disturbances is a very important issue. Every disruption in production process also affects the economics of this process. Therefore, robust scheduling certainly can be applied to real systems where there are unplanned machine breakdowns or change in the time of ongoing operations.

The concept proposed by the authors is the subject of ongoing research and analysis to develop a methodology of robust scheduling and software for generating schedules for discrete manufacturing processes.

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