The tool supporting decision making process in area of job-shop scheduling

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Abstract. Today most manufacturing companies from machine building industry are operating in single unit or short-run production which is very complex in terms of decision making processes in production planning area. The difficulty in decision making in the area of scheduling is caused by the necessity of analysing multiple factors and evaluating various scheduling options due to numerous criteria. The article presents the author's tool supporting decision making in the area of job-shop scheduling. The tool introduced in the article enables scheduling based on author's priority rule allowing maximum usage of the most loaded resource (known as critical resource), which determines efficiency of the production system. The tool has been designed and verified as a part of PhD dissertation research.

Keywords: job-shop scheduling, decision making process, interactive application

1   Introduction

In contemporary world efficiency of manufacturing companies depends not only on production resources available, but also on how well they are used. The problem of using resources the right way is strictly connected to the problem of scheduling production flow. The fact that there are numerous external as well as internal factors influencing production processes makes production scheduling a very complicated issue. Available literature analysis shows that the scheduling problem is one of the most important and complicated problems which has been known as NP-hard and very challenging combinatorial optimization problem since 1950s [1,2] in machine scheduling. With such high complexity of the problem and in keeping with goal criterion which usually is to minimize the time of every operation in a given process it is difficult to find acceptable solution [3] and in most cases an optimum solution cannot be found in reasonable time [4].

Today most manufacturing companies from machine building industry are operating in single unit or short-run production which is very complex in terms of decision making processes in production planning area. Range of manufactured products in single unit as well as in short-run production is usually very wide and very unstable at the same time. It is very difficult to predict demand and probability of spreading potential orders over time in advance. On top of that, average time frame from the moment an order is placed to its completion gets shortened [5,6,7]. Decisions made in the production planning area relate to balancing manufacturing capacity in terms of quantities, quality, delivery dates and costs of production with customer's requirements. The necessity of analysing numerous factors causes manufacturing companies to use tools helping with decision making in the area of scheduling processes.

2 Job-shop scheduling

The first function of business management is planning, which is based on an optimal development of work time and resources [8]. Production planning is done as part of a hierarchical planning process, where the production plan is cascaded down to a more detailed production schedule. The objective of scheduling is to schedule or sequence production tasks, in order to minimize a certain performance measure of customer satisfaction [9].

Scheduling algorithm is selected based on production system characteristic, set of orders to be executed and on encountered constraints. Among scheduling algorithms available in literature on the subject there are two types of scheduling systems: simple and complex. The simple scheduling system is described as single-machine scheduling and parallel-machine scheduling, while the complex system is described with the use of flow-shop scheduling, job-shop scheduling and open-shop scheduling. Numerous scientific publications concerning production tasks prove that job-shop scheduling problems are a current research problem.

Job-shop scheduling problem consists of a finite jobs set, Ji(i=1,2,...,n) to be processed on a finite machine set Mk(k=1,2,...,m) [10]. According to its production routine, each job is processed on machines with a given processing time, and each machine can process only one operation for each job [11]. Job-shop scheduling can be thought of as the allocation of resources over a specified time to perform a predetermined collection of tasks [12]. Researchers developed several methods to deal with the job-shop scheduling problem. Scheduling problem solving methods can be divided based on type of generated solution into exact methods and approximation methods.

Scheduling problem solving exact algorithms can be used on condition that the system structure is defined, certain task types and certain constraints are defined. The general approach of these methods is to consider the problem in its total system form of scheduling *n* jobs on *m* machines. In the literature on the subject exact algorithms are solved with the use of mathematical programming. Mathematical programming is an optimization problem with conditions constraining decision making and a goal function being a decision making evaluation criterion. There are a few methods of

mathematical programming, such as: partial enumeration, linear programming, integer programming, dynamic programming, branch and bound, branch and dominate [13-15]. Exact methods of scheduling problem solving are applicable in a small group of defined problems, where every solution can be assessed. With the increase of complexity of a problem, waiting for solution time is extended and a need to use high computing powers machines arises.

Approximation methods, also known as heuristic methods, do not guarantee finding optimum solution, however, they allow finding acceptable solution in a shorter time that exact algorithms. Shorter time needed for finding solution causes that these methods are used in real production systems, where planning multiple complex manufacturing orders with numerous constraints are needed. In the literature on the subject the following heuristic methods can be found [13,16]:

    - local search methods, e. g. ant colony optimization or tabu search,

    - evolutionary methods, e.g. genetic algorithm or differential evaluation,

    - constructive methods, e.g. priority despatch rules.

The above methods are widely described in literature. The solution presented in this article is one of heuristic methods and is based on priority rules.

Priority rules indicate how to assign a specific job to a specific machine at a given time, when a machine becomes available for process [17-20]. Literature [21,22] classified over 100 priority rules.

During scheduling process, the major issue is choosing appropriate priority rules that will help achieve projected criterion. There are multiple studies comparing how priority rules work in job-shop scheduling [22-24]. For example, minimizing manufacturing process cycle criterion is best achieved with the use of the shortest operation time rule and with the minimal sum of weighted task time.

Scheduling quality measure is represented by goal function created on the base of evaluation criterion. Main criteria of scheduling evaluation are completion times and delivery times parameters. Most common scheduling evaluation criteria are [6,22,25-27]:

- minimizing total manufacturing time, known as minimum makespan C_{max}
- minimum average makespan, $C_{śr}$
- minimizing maximum flow time, J_{max}
- minimizing maximum delay, L_{max}
- minimizing average delay, $L_{śr}$
- maximum delay, $T_{max,}$
- average delay, $T_{śr,}$
- maximum flow time, $F_{max,}$
- average flow time, $F_{śr.}$

Newest literature sources on job-shop scheduling have been collected in studies [14, 28], in which the authors research problem solving methods paying special attention to their influence on scheduling evaluation criteria.

Job-shop scheduling problem and adopted building schedules criteria have been described in [29-31]. Due to the large number of criteria to be considered in scheduling problem, it is recommended to used methods supporting decision-making, which effectiveness is proven in numerous publications [32-40]. Useful tool helping decision making in the area of scheduling is simulation. Simulation can be applied to many aspects of manufacturing systems [41]. In job-shop scheduling the simulation of

dispatching rules and the assessment of the effect of different rules on the shop's ability to meet delivery dates and utilize the machines. The first application of simulation was computer simulation studies of different priority rule have been carried out. Today many of such methods are available through integrated scheduling systems. Examples of such systems, available and free to be used through the Internet, include the LEKIN [42], and Lisa [43], among many others.

For example popular LEKIN Software is a tool with the main purpose of introducing the main scheduling theory and demonstrating the capabilities of several scheduling methods [44].

However, author's tool supporting decision making in job-shop scheduling presented in this paper is a computer application allowing generating schedules in accordance with a chosen priority rule and then comparing results with chosen criteria.

3 An interactive scheduling application

Developed computer application takes the form of interactive scheduling system for machine environments, which can be used for scheduling tasks in real life manufacturing or in research, as it has an option of generating sets of orders. The generator allows to define quantity of orders in each set and number of production operations in each order. Duration of each production operation and workstation where each operation takes place are chosen with equal probability from a defined set of numbers. However, in case sets of orders are entered into the system individually, it is possible to define every single parameter of production orders.

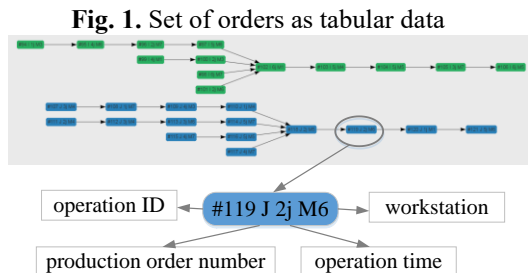**Fig. 1.** Set of orders as tabular data

Fig. 2. Set of orders as pictorial data

Set of production orders is presented as a table (Fig.1) containing:

- production order number
- operation time
- workstation, where an operation is realized
- next operation
- previous operation

and graphically (Fig.2) presenting the structure of each order.

The application allows to generate a schedule created in keeping with the chosen priority rule:

- Shortest task time (STT), a local and static rule that minimizes average task production cycle [45-47].
- Longest task time (LTT), which maximizes average production cycle as well as average number of tasks waiting in queues. However, for job-shop task set it minimizes average workstation-consumption of operations waiting in queues thanks to the fact that the highly workstation-consuming operations are realised faster [22].
- Shortest processing time (SPT), a local and static rule which minimizes average task production cycle and percentage of delayed tasks in job-shop order sets [22, 48].
- Longest processing time (LPT) is a local static rule that has a proven efficiency for production systems with numerous machines and production equipment. LPT also minimizes makespan for simple systems.
- First in first out (FIFO) causes waiting time of operations in queues to extend and, at the same time, extending production cycles times [22].
- Priority rule for the smallest total workstation-consumption of workstation orders from the set of chosen chains of workstation orders realized before the critical resource (CR)

Priority rule for the smallest total workstation-consumption of workstation orders from the set of chosen chains of workstation orders realized before the critical resource is the author's priority rule designed for a PhD dissertation. Critical resource is defined as production system resource, which due to work load in job-shop set of production orders determines the efficiency of the whole production system. The superior characteristic of the critical resource among all production workstations is the highest labour-hour load. The designed priority rule demands that from all waiting orders the one with the smallest total workstation order realization time of orders in given chains is chosen.

Own research showed that applying the priority rule for the smallest total workstation-consumption of tasks in the set of chosen chains of operations realized before the critical resource maximizes the usage of the critical resource, which leads to shortening of the average time of realization of a production order set.

The result of scheduling for each of the chosen priority rules is generated graphically as schedule (Fig.3) and as tables containing information concerning:

- order number,
- order start time ,
- order end time,
- total time of an operation in a certain order,
- time of a machine work load start,

- time of a machine work load end,
- total machine working time,
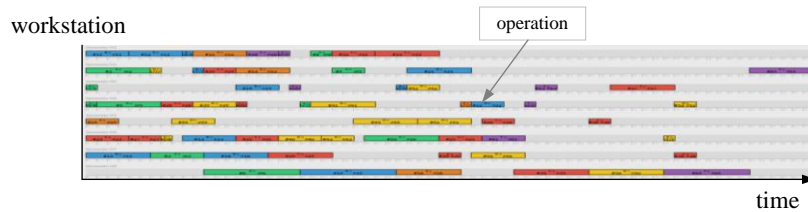- total time of machine pauses.

workstation

operation

time

Fig.3. Results presented graphically

Collective results concerning scheduling developed for a given set of production orders in keeping with all available in the application priority rules are presented in the form of a table in spreadsheet MSExcel (fig.4). The table contains information concerning makespan (C_{max}), critical resource work load (wCR) and the amount of work in progress (WIP). Decision-maker gives validity all criteria by determining their weights. The weights can be from 1 to 5. The application create the ranking takes into account all the criteria simultaneously.

		priority rules					
	weight	STT	LTT	SPT	LPT	FIFO	CR
C_{max}	5	35	38	37	42	45	32
wCR	2	10	14	11	12	17	8
WIP	3	20	18	25	19	20	20

C_{max}		175	190	185	210	225	160
wCR		20	28	22	24	34	16
WIP		60	54	75	57	60	60
total		255	272	282	291	319	236

ranking		2	3	4	5	6	1

Fig.4. Spreadsheet

The application helps production planner to make decisions in choosing the best schedule for a certain set of orders in keeping with chosen criteria. The possibility of manually modifying weights of each criterion of evaluation makes the application versatile and allows it to be used in a variety of production conditions. The versatility of the application is also proven by the fact that the critical resource can appear multiple times and at any stage of technological process in the structure of a given production order. It is assumed though that the operation realized with the use of the critical resource must not be repeated between the first and the last operation of the same path. Currently works on expanding the application's capabilities with the module allowing rescheduling are being conducted.

4 Conclusion

The tool supporting decision making introduced in this article has been designed as a part of research for a PhD dissertation at Poznan University of Technology. The tool was preliminary implemented in three manufacturing companies in Greater Poland area. The companies confirmed the efficiency of the described tool in supporting decision making in the area of production scheduling.

The application is also successfully used for research in the area of job-shop scheduling. Currently works are conducted on defining rules for scheduling conversion and adding a rescheduling module to the already designed application.

Ac1knowledgment

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