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INTRODUCTION OF A NEW PERFORMANCE MEASURE FOR JOB SHOP SCHEDULING

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ABSTRACT
Scheduling as a research area is motivated by questions that arise in all situations in which scarce resources have to be allocated to activities over time. The quality of a schedule may be evaluated by various optimality criteria.
This paper is aimed to research the impact of job shop scheduling on value stream optimization and decreasing of cost-time investment. Value stream mapping represents a very efficient tool for visualization of activities within the production flow focused on activity duration with the purpose to eliminate non-value added activities. Cost-time profile is a powerful tool for visualization and calculation of cost accumulation during the time across the entire production flow. Using the Cost-Time Profiler software for simulating the impact of different schedules on total production cost and cost-time investment (representing the time value of money) we prove that scheduling has essential influence on changes of cost-time investment. Original contribution of the paper is the suggestion of the minimum cost-time investment as a new scheduling objective function, which should be included in scheduling software solutions.
Keywords: job shop scheduling, objective function, cost-time investment

1. INTRODUCTION
Scheduling is a decision-making process used on a regular basis in many manufacturing and service industries. These forms of decision-making play an important role in procurement and production, in transportation and distribution, and in information processing and communication. The scheduling functions in a company rely on mathematical techniques and heuristic methods to allocate limited resources to the activities that have to be done. This allocation of resources has to be done in such a way that the company optimizes its objectives and achieves its goals [1].
The processes of job shop production are comprised of a large number of operations which are sequenced in different order, and are performed on a large number of different jobs, whose capacities are not usually synchronised. A typical production unit is comprised of groups of machines, arranged according to technological similarity. With this type of organisation there is always incompatibility between technological and transport flows, and the capabilities of individual technologies. The

material is ordered according to demand; the production is done, in entirety, after receiving the order, which creates very long due dates. Only appropriate organisation and adaptable, sustainable technology can guarantee appropriate competitiveness [2, 3].
The quality of a schedule may be evaluated by various optimality criteria. The basic objective is to find a feasible schedule that minimizes some performance measure depending on the completion time of the last operation of each job. Let us denote by S_i the starting time of job i, $i = 1, \ldots, n$, by C_i the completion time of job i, $i = 1, \ldots, n$. The most common optimality criteria are the makespan C, defined by eq. (1) and the total flow time F, defined by eq. (2). Job flow time is the length of time job spends in the system. Both criteria belong to the group of completion time oriented optimality criteria.

$$C_{max} = \max \{C_i\},\ 1 \leq i \leq n \quad \ldots (1)$$

$$F = \sum (C_i - S_i),\ i = 1, \ldots, n \quad \ldots (2)$$

Other objectives are: maximum tardiness, total tardiness and total weighted tardiness, minimization of the number of tardy jobs, or the weighted number of tardy jobs [4].

2. METHODOLOGY BACKGROUND

Companies should map value stream in order to see sources of waste and value. **Value stream mapping** is an essential tool for processes visualization that helps to understand material and information flows and see more than waste. The main goals of value stream management are: waste elimination from the production processes and operation, reducing the time in the processes, cost reduction and quality improvement [5].
The term **cost-time profile** was first time mentioned by Fooks [6]. He defined cost-time profile as a diagram of cash accumulation during each unit of time across the entire business cycle (from negotiating an order and entering it, to pre-manufacturing design and information gathering processes through manufacturing, to shipment and receivables) and this profile is a cash oriented diagram.
Cost-time profile is a graph that shows how much money was spent for the production of the product and how much time elapsed from process start to end, until the money came back through the sale [7]. Cost-time profile discovers new opportunities for improvement and helps, how to evaluate and select measures to achieve the improvement. Cost-time profile diagram needs information about process, cost and activities and has three components (as shown in Fig. 1): (1) material (including services and information), (2) labour and (3) wait [8]. Labour component is usually named "activity".
Cost-time investment (*CTI*) is the area under the curve and that is the amount of cost spent in the product manufacturing multiplied by the time that product spent in system before sales.

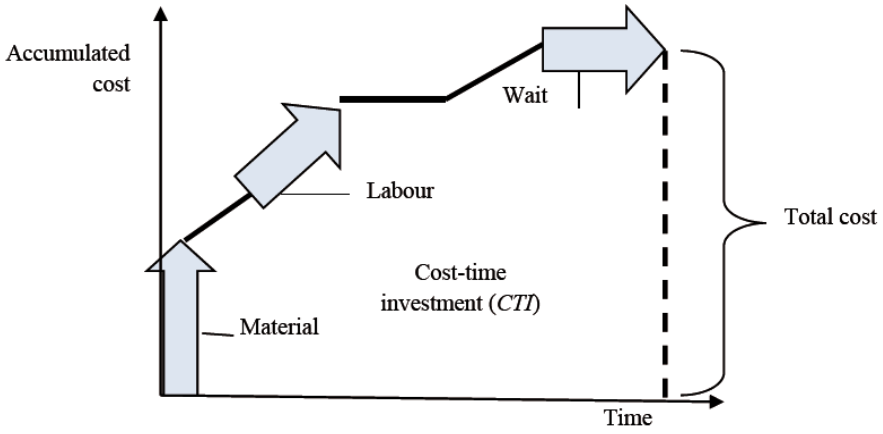

Figure 1. Cost-time profile diagram.

3. INTRODUCTION OF A NEW PERFORMANCE MEASURE

Cost-time profile shows cost accumulation during the time, so we used this tool to simulate different scenarios with implementation of different schedules. We started with the data sample for a job shop consisting of five machines and seven jobs (all with the same weight) – see the data given in Table 1. Rows contain in the last column the order of operations for each job: each entry contains the index of machine and the processing time on it.

Table 1. Input data for scheduling (sample).

Jobs	Release date	Due Date	Machines/Processing Times				
A	0	39	1/7	2/6	3/8	4/9	5/4
B	0	42	2/3	1/8	5/3	3/8	4/9
C	0	41	3/3	2/7	1/7	5/9	4/7
D	0	41	2/3	1/4	3/9	4/3	5/3
E	0	36	2/5	3/4	5/4	4/2	1/7
F	0	40	2/9	1/2	3/8	4/9	5/6
G	0	38	5/8	2/9	4/6	3/2	1/3

We used these input data to calculate the beginning and the end times for each of 7 jobs (A to G). Dispatching rules applied for this research were: Earliest Due Date (EDD), Critical Ratio (CR), Minimum Slack First (MS) and Shortest Processing Time (SPT). For this stage of research we used *Lekin Scheduling System* to construct the schedules (see the Gantt charts in Fig. 2 a-d).

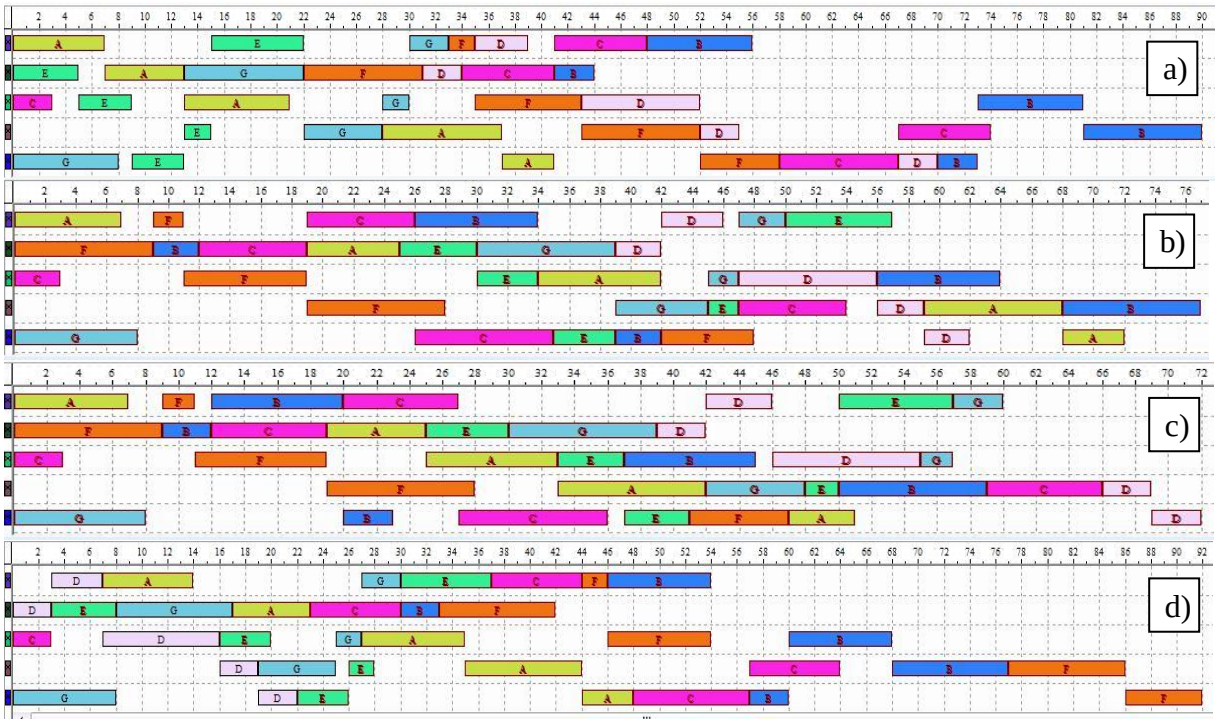

Figure 2. Gantt charts for the applied rules, a) EDD rule, b) CR rule, c) MS rule, d) SPT rule.

In the next step we calculated and simulated the cost-time profiles and cost-time investments under different conditions, defined by the schedules. Software used for this purpose is *Cost-Time Profiler* (developed by a project team from Virginia Tech – Centre for High Performance Manufacturing) for data capture, calculations and graphic output. Beside the data of start and end time for each job, we had to assign other relevant data such as material cost and labour cost for each job, respecting value stream costing rules. Cost-time profile simulation for the MS rule is presented in Fig. 3. In Table 2 we present the summary of the various performance measures of the schedules.

Table 2. Summary of the various performance measures of the schedules.

Rule	Makespan	Maximum tardiness	Total number of tardy jobs	Total flow time	Total tardiness	*NEW:* Cost-time investment
EDD	90	48	**5**	389	130	38729
CR	77	35	7	421	143	35486
MS	**72**	**31**	7	413	135	**32247**
SPT	92	52	**5**	**370**	**120**	41709

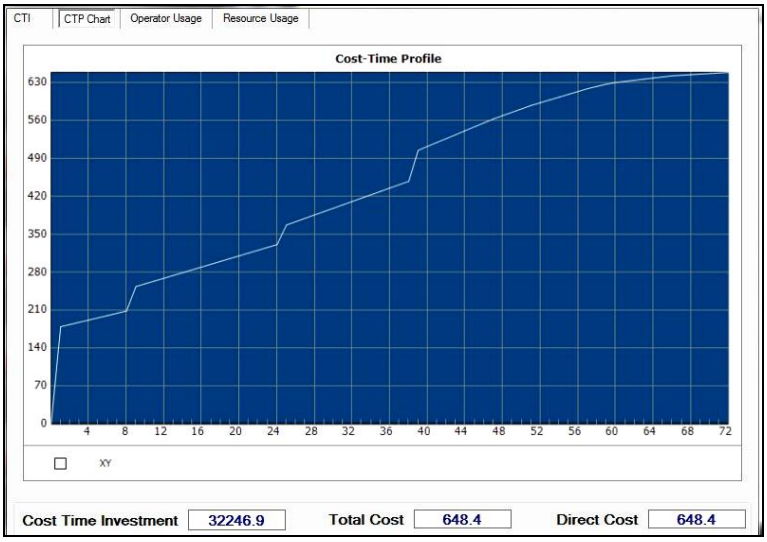

Figure 3. Cost-time profile for the MS dispatching rule (best CTI result).

4. DISCUSSION

After the analysis of proportion between minimum and maximum values of cost-time investment, we find out a difference of almost 30 %. This is a really significant indicator and it could be a very useful tool for value stream optimization. We can find (even on so small experimental sample) very different optimal rules for the objective functions (see the bolded values in Table 2).

Using the results of the cost-time profile simulation enables us to set an additional scheduling objective function: cost-time investment (*CTI*), which is really important in achievement of lean manufacturing efforts. We recommend to scheduling software developers to add the parallel cost-time profile simulation and include the *CTI* as a scheduling performance measure in their software solutions.

5. CONCLUSION

Companies have to increase the effectiveness of production to guarantee lower costs and on-time delivery and to meet customers' satisfaction. In the paper we emphasize the importance of relationship between money and time. Cost-time profile could be a useful tool for making selection among different strategies.

For the next research, we are planning to use more detailed machines' related data such as: price, life-time, maintenance cost and daily usage, in combination with other measures such as reduction of material and operation cost.

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