EFFECTIVE APPROACH TO JOB SCHEDULING IN THE RECYCLING PROCESS WITH DIFERENT TYPE OF MANUFACTURING MACHINES

Ján Zelenka

Institute of Informatics / Slovak Academy of Sciences, Dúbravská cesta 9, 845 07, Bratislava Slovakia,

Abstract

Currently, materials flow optimization and creating of optimal job scheduling are one of the main tasks of all company for increase of competitiveness. A schedule problem in a manufacturing company is characterized as jobs sequence and allocation on machines during a time period. The first part of this article is focused on dynamic scheduling and its methods. The second part describes a case study of dynamic scheduling in a manufacturing company on recycling of plastic materials realized by APVV project number VMSP 0168/09. The manufacturing company described in this article is focused on recycling-based polymerization of plastic waste and on plastic waste bags production.

A multi machine job shop scheduling problem is to assign each operation to a machine and to find a sequence of jobs (operations) on machines that the maximal production time is minimized [1].

1 Mathematical formulation of a schedule task

For solving a schedule task must be defined mathematical formulation of the schedule task. The schedule task can be defined by three sets:

- set of jobs $J = \{1, 2, \ldots, n\}$;
- set of machines $M = \{1, 2, \ldots, m\}$;
- set of operations $O = \{1, 2, \ldots, N\}$.

Finite sequence of operations which must be made within one order represents one job. One operation is a basic unit of technological process, and it is characterized by type and processing time. In case that the operation can be made on several machines, processing time for all machines must be determined. Creation of job schedule must meet some restrictions, which we divide to hard and soft restrictions. Hard restrictions represent the technological process. They describe restrictions of individual operation time dependence, manufacturing machine capacity and other manufacturing machine characteristics. Soft restrictions represent the preferences which need not be fulfilled, but from the scheduling point of view it is convenient to fulfil them. The correct definition of soft restrictions we can reduce the searching space and find better solution of the job schedule. Preferences are an operation sequence which can minimize downtime or the waste due to changing of manufacturing parameters. The time continuity of several operations is expressed by the preference $O_i \prec O_j$, where operation O_j cannot start earlier than the operation O_i finishes. Other technological restrictions of processing of operations on machines can be described as follows:

- an operation can be made on one machine only;
- an operation can be atomic, it means the producing process of operation cannot interrupted by an arrival of other operation;
- it is specified in several processes, that two operations cannot be made on one machine at one time unit.

Every job can be specified by next input information (Mičunek 2002):

- operations O_i processed on machines;
- processing time p_{ijk} is the time to process j^{th} operation, i^{th} job on k^{th} machine;
- r_i is the time when it is possible to start processing job J_i;
- d_i is the required end time of job J_i;
- a_i is maximal allowed time of a job in the system $a_i = d_i - r_i$;
- w_i is the weight of job importance J_i.

Output information of a scheduling problem represents the data, which can be calculated for every job J_i of the job schedule. The information consists of the following data:

- C_i is the end time of job J_i;
- F_i is the processing time of job J_i;
- W_i is the waiting time of job *Ji* in the system;
- L_i is the delay calculated by $L_i = C_i - d_i$;
- T_i is the maximal $\{0, L_i\}$ delay of job J_i ;
- E_i is the maximal $\{0, -L_i\}$ advance of job J_i;
- $U_i = 0$, if $C_i <= d_i$, else $U_i = 1$ is penalty function of job J_i.

The task defined in this way belongs to the optimization field. Optimal (suboptimal) solution of the job schedule is found if several criterions and restrictions are valid. Traditional approach of static schedule assumes static environment and does not assume failure of machine. Real manufacturing system assumes several types of unpredictable events that result in the creation of a new job schedule. According to (Vieira et al., 2003) in manufacturing systems there are two types of events in real time:

- events related to source (failure of source, material ageing, human operator, etc.);
- events related to job (new jobs arrival, changing job priorities, changing job deadline, etc.);

According to (Metha and Uzsoy, 1999; Vieira et al., 2000a, 2003; Aytug et al., 2005; Leus and Herroelen, 2005), dynamic scheduling is divided into four basic types:

- reactive scheduling;
- predictive-reactive scheduling;
- predictive-reactive (robust) scheduling;
- proactive (robust) scheduling.

Solution of dynamic scheduling problem can be broken into a series of static problems to be dealt with static scheduling methods. Depending on when we need to create a new job schedule, we use scheduling at regular intervals (rescheduling), upon arrival of new event (event rescheduling), or the hybrid way, when new job schedule is created periodically but in case urgent event arrives for job scheduling new job schedule is created. Dynamic scheduling uses five basic approaches for job scheduling:

- dispatching rules;
- heuristics;
- meta-heuristics (Tabu search, simulated annealing, genetic algorithm);
- artificial intelligence (neural networks, case-based reasoning, fuzzy logic, Petri nets);
- Multi-agents systems.

Dispatching rules - the literature describes several types of rules, from simple to very complex rules. No set of rules can capture the complexity of scheduling requirements in dynamic environment. Therefore, to verify the efficiency and effectiveness of the rules simulation techniques are used. Experimental results show that the correct choice of rules depends not only on the characteristics of the manufacturing machines, but also on other factors, such as material flow, etc.

Heuristics – this is a frequently used approach in dealing with scheduling tasks. In combination with the set of dispatching rules, it very significantly may contribute to finding appropriate solution to scheduling tasks.

Meta-heuristics - this technique includes methods such as Tabu search, simulated annealing or genetic algorithms. All methods have been used successfully to solve different types of scheduling tasks.

Artificial intelligence – this field includes methods such as knowledge-based systems, neural networks, case reasoning, fuzzy logic, Petri nets, etc. The use of the technology is very successful in the field of machine learning and adaptive learning.

Multi-agent systems - MAS technologies are among the most progressive evolving technologies, from which we expected major benefits in addressing the job scheduling. Initial expectations have caused frustration and certain scepticism in the application of this theory into practice. Nevertheless, this approach is still a current topic, especially in research toward the development of comprehensive, robust and cost-effective solutions for businesses new generation.

The following part of the article describes an approach to solving job scheduling based on a real manufacturing company problem.

2 Description of the real manufacturing system

The manufacturing system which is the carrier of the APVV project No. 0168/09, with significant share in Slovak market, is dealing with producing of recycled low-density polyethylene (LDPE) film. Recycling capacity is 180 tons per month. The manufacturing company is one of the three largest companies in Slovakia from the point of view of recycling waste film. Manufacturing machines for recycling of soft plastics are used as a pilot application for the output of research carried out in cooperation with the Institute of Informatics of Slovak Academy of Sciences (II SAS) in a joint applied research project. This project resulted from years of research in modeling and simulation of manufacturing machines at the II SAS.

The manufacturing system itself consists of several different machines recycling plastic materials and producing waste bags from LDPE film. Block diagram of the manufacturing system is shown in Figure 1. The system consists of three main parts:

- granulation machine: polymerization of waste plastics leads to production of different color granulates ("wet production");
- blowing machine (extruder): the polymerization process using granulates and other input additives produces LDPE film of desired shape, thickness, width and color (four different blowing machine types – extruders are available); the film is scrolled into rolls (maximum roll weight depends on blowing machine type);
- scroll machine: LDPE film is welded, punched and scrolled to desired size (two different scroll machine types are available).

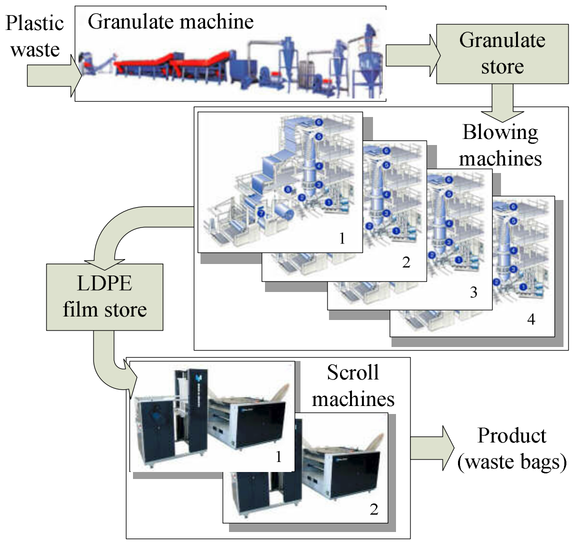

Figure 1: Block diagram of the manufacturing system

The manufacturing system is defined by the following set of jobs:

$$J = \{J_{gran}, J_{fol}, J_{vrec}\};$$

where J_{gran} represents granulate production, J_{fol} represents the production of LDPE film roll and J_{vrec} represent the production of waste bags from LDPE film. Every job is defined by the following operations:

$$J_{gran} \to \{O_{gran}\};$$
$$J_{fol} \to \{O_{gran,} O_{vyf}\};$$
$$J_{vrec} \to \{O_{gran,} O_{vyf}, O_{rol}, O_{bal}\};$$

which can be divided into the following set of machines:

$$O_{gran} \to \{M_{gran}\};$$
$$O_{vyf} \to \{M_{ex1}, M_{ex2}, M_{ex3}, M_{ex4}\};$$
$$O_{rol} \to \{M_{rol1}, M_{rol2}\};$$
$$O_{bal} \to \{M_{bal}\}.$$

3 Optimization task

In this case, the task of optimization in this case is to establish the optimal schedule for each manufacturing machine, so that all jobs are made on time, downtime of individual machines is minimized, to reduce waste generated by blowing or scroll machines and to reduce power demand. The optimization is aimed at increased flexibility, reduced cost and improved product quality. Currently, a job scheduler is able to create short-time job schedules only, about 5-7 days, due to intuitive human decision. A possibility to find the optimal job schedule is to search the entire area of possible combinations of loaded jobs operations. If the number of loaded jobs to produce a granulate J_{gran} is n, the size of possible combinations area is n factorial combination, but in case of n jobs to produce waste bags J_{vrec} the number of possible combination will increase to $(n!)^2 8^n$ combination. Let us assume that each operation may be made on each machine, defined for this operation. The possible combination area is large. For example, for two jobs of J_{vrec} the size consists of 256 combinations, which has a negative impact on computational capacity. The size of searched space is reduced by applying a set of preferences. In our case, the set of preferences is defined by the following preferences:

$$\left\{ \begin{matrix} O_{gran_i} \prec O_{vyf_i}; O_{vyf_i} \prec O_{rol_i}; O_{rol_i} \prec O_{bal_i} \\ O_{gran_i} \prec O_{bal_i}; O_{vyf_i} \prec O_{bal_i}; O_{gran_i} \prec O_{rol_i} \end{matrix} \right\}$$

To solve the scheduling problem in real manufacturing company, the time for calculating new job schedule is very important. Scheduling by the job level reduces the searched space, but at the cost of finding suboptimal solution. In this case, the searched space has only n factorial combination. This is why we will find only suboptimal solution.

There are a number of software tools allowing the simulation of manufacturing systems and optimization of material flow on the market. The use of unconventional scheduling methods is very hard or impossible with these tools, therefore new software application in MATLAB programming environment has been created. This application allows to simulate a manufacturing process and to find suboptimal (optimal) solution of the schedule.

4 Description of software application

This application (see Fig. 2) allows to simulate the production of waste bags, LDPE film or granulate. We can set different parameters of the blowing or scroll machines, the days when production is stopped (holidays, vocations, etc.), various dependences (for example: the dependence of film blowing speed upon film thickness for each blowing machine separately, the dependence of film blowing speed upon to a blown film quantity, etc.). On the basis of a set parameters and loaded order (an application allows to load orders for production of granulate, LDPE film and waste bags in this time) the simulation we get suboptimal (optimal) job schedule solution so that all orders will be done to the delivery time.

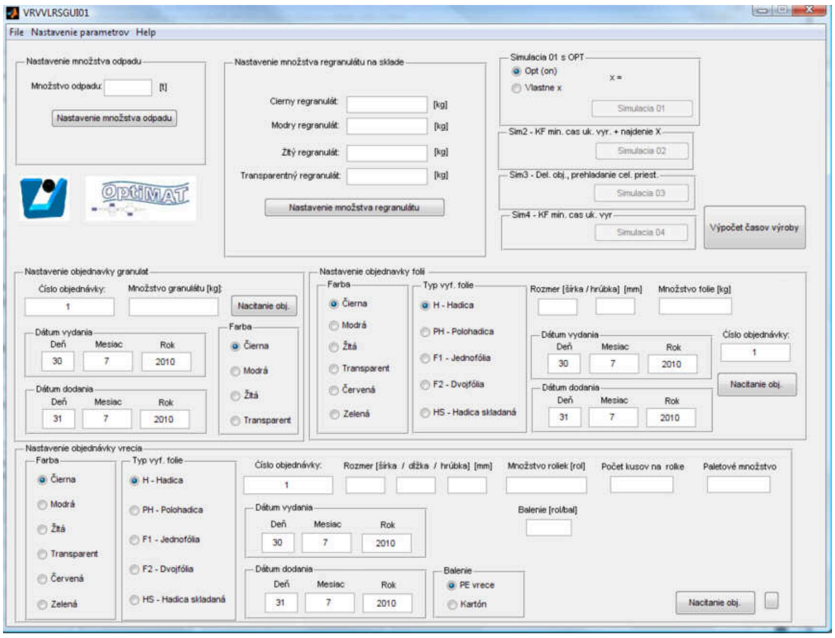

Figure 2: Graphical user interface of MATLAB software application

For example, simulation of three jobs $(J_{vrec_1}, J_{vrec_2}, J_{fol})$, optimal solution of job schedule was calculated for 3,6 hours and the calculation of suboptimal solution took 23 seconds. The calculating time to find the suboptimal job schedule of five (seven) jobs J_{vrec} took approximately 16 minutes (19,4 hours). The simulation result (see Fig. 3) is the job schedule of individual operations in written or graphical form (Gantt graph).

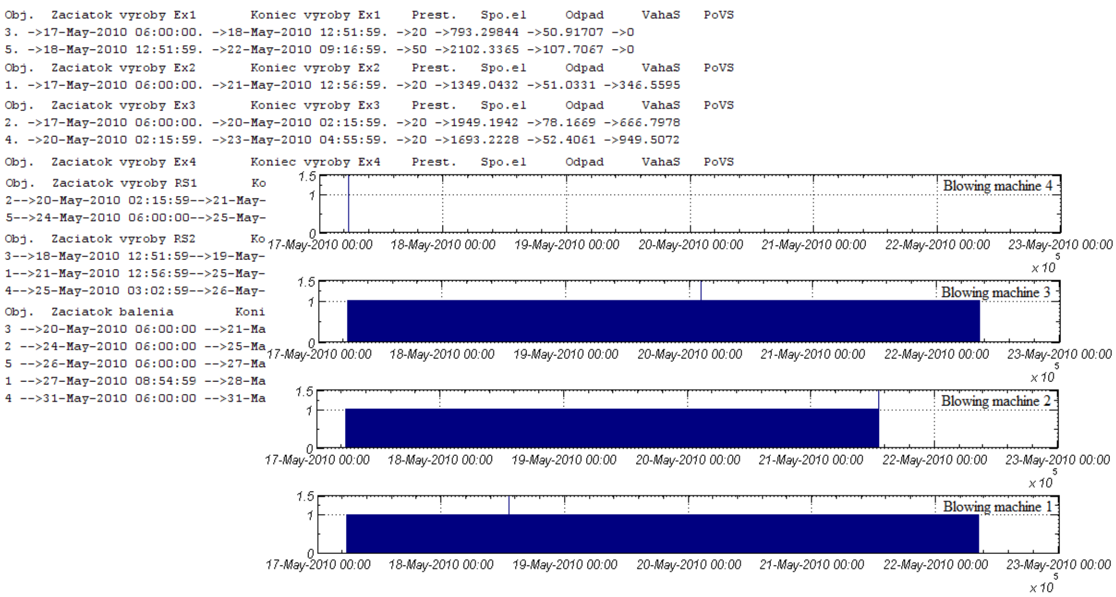

Figure 3: The simulation result in written or graphical form

In case of jobs scheduling for the production of waste bags J_{vrec} the following optimization can be considered. Loaded job J_{vrec} contains information about the weight of LDPE foil which must be blown. Blown film is scrolled to roll of desired weight (it depends on the blowing machine type), which is later processed on the scroll machine. The blowing process is a continuous process and material losses occur when by changing the film roll. We must count with the material loss when creating the job schedule. As soon as the LDPE film roll is produced, it can be processed on the scroll machine. The production time of LDPE film roll depends on blown film width and thickness and on blowing machine type. The processing time of LDPE film roll depends on the thickness of film, number of waste bags on the roll and on scroll machine type. In case if LDPE film roll processing on the scroll machine starts immediately after being produced and the LDPE film roll processing time on the scroll machine is greater than or equal to the production time of LDPE film roll, it is possible to start to process LDPE film roll on the scroll machine without downtime. Otherwise, when the processing time of the scroll machine is less than the production time of the blowing machine, the scroll machine must wait for the production of the film roll. The scroll machine will be unnecessarily reserved (downtime occurs, which must be reduced). The reality is that the processing time of the scroll machine is less than the production time of the blowing machine.

This application allows to compare three approaches of LDPE film roll processing:

- the first way is that the film roll will be processed on the scroll machine after production of the xth film roll on the blowing machine (model created in SimEvents and simulation results can be found in [8]); this approach can be used only if the precedence $O_{vyf_i} \prec O_{rol_i}$ will be limited and operation O_{rol_i} will have to follow operation O_{vyf_i}; this way, the size of searching space and downtime on the scroll machine are raduced;
- in the second way, all combinations of operation loaded jobs are generated; the size of a searching space is reduced by applying a set of preference; this way allows to find the optimal solution of the job schedule;
- the third way is similar to the previous way, but the searching space contains all combinations of jobs; this way allows to find only suboptimal job schedule solution.

Results of the above approaches for the two jobs J_{vrec} are given in Table 1.

Table 1: SUMMARY OF RESULTS

Searching space		
First approach *(2 combinations)*	*Second approach* *(70 combinations)*	*Third approach* *(2 combinations)*
$O_{gran_1}O_{vyf_1}O_{rol_1}O_{bal_1}O_{gran_2}O_{vyf_2}O_{rol_2}O_{bal_2}$ $O_{gran_2}O_{vyf_2}O_{rol_2}O_{bal_2}O_{gran_1}O_{vyf_1}O_{rol_1}O_{bal_1}$	$O_{gran_2}O_{vyf_2}O_{rol_2}O_{bal_2}O_{gran_1}O_{vyf_1}O_{rol_1}O_{bal_1}$ $O_{gran_2}O_{vyf_2}O_{rol_2}O_{gran_1}O_{vyf_1}O_{rol_1}O_{bal_1}O_{bal_2}$ $O_{gran_2}O_{vyf_2}O_{rol_2}O_{gran_1}O_{vyf_1}O_{rol_1}O_{bal_2}O_{bal_1}$ $O_{gran_2}O_{vyf_2}O_{rol_2}O_{gran_1}O_{vyf_1}O_{bal_2}O_{rol_1}O_{bal_1}$ $O_{gran_2}O_{vyf_2}O_{rol_2}O_{gran_1}O_{vyf_2}O_{bal_1}O_{rol_1}O_{bal_1}$ .... $O_{gran_1}O_{vyf_1}O_{rol_1}O_{bal_1}O_{gran_2}O_{vyf_2}O_{rol_2}O_{bal_2}$	$O_{gran_1}O_{vyf_1}O_{rol_1}O_{bal_1}O_{gran_2}O_{vyf_2}O_{rol_2}O_{bal_2}$ $O_{gran_2}O_{vyf_2}O_{rol_2}O_{bal_2}O_{gran_1}O_{vyf_1}O_{rol_1}O_{bal_1}$
Calculating time of schedule		
6.2 seconds	181.05 seconds	4.9 seconds
Start and end times of production of the jobs		
J_{vrec_1} 2.8.2010 18:29:59 10.8.2010 08:08:00	J_{vrec_1} 2.8.2010 06:00:00 11.8.2010 08:08:00	J_{vrec_1} 2.8.2010 18:29:59 11.8.2010 08:08:00
J_{vrec_2} 2.8.2010 06:00:00 9.8.2010 06:54:00	J_{vrec_2} 2.8.2010 15:33:59 10.8.2010 06:54:00	J_{vrec_2} 2.8.2010 06:00:00 10.8.2010 06:54:00
Power demand		
5889.6036 kW	6440.102 kW	5851.7203 kW
Comparison with the third approach		
J_{vrec_1} -11.67% J_{vrec_2} -12.44%	J_{vrec_1} 0% J_{vrec_2} 0%	J_{vrec_1} - J_{vrec_2} -
Advantages		
- 12 % savings time - low calculating time	- complete searching space is generated	- low calculating time
Disadvantages		
- complete searching space is not generated - the size of searching space is limited to 12 jobs	- ong calculating time - the searching space size is limited to 12 operation of loaded jobs	- complete searching space is not generated - the searching space size is limited to 12 jobs

5 Conclusion

The article gives a view to job scheduling problems in a manufacturing system and presents a problem - solving in a real manufacturing system by using the MATLAB software tool. The introduced solution has some restrictions associated with using the function which generated the searching space. Currently it is possible to find job schedule only 12 jobs using the first or the third approach.

It is evident from the simulation of three approaches that the first approach is better than the second or third one, but only if the processing time on the scroll machine is shorter than the production time of the blowing machine, and if the processing of film roll can start on the scroll machine after having produced the x^{th} film roll on the blowing line. Accordingly, it is possible to divide one job to two blowing machines, and thus to reduce the production time. However, job scheduling with short production time is not necessarily the optimal solution from the point of view of finances; therefore it is necessary to find the optimal (suboptimal) job scheduling solution satisfying all conditions (production time, downtime, finance, power consumption of all machines, etc.).

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Ján Zelenka
Institute of informatics / Slovak Academy of Sciences, Dúbravská cesta 9, 845 07, Bratislava Slovakia, e-mail: jan.zelenk@savba.sk