10.2478/v10170-011-0032-0

Archives of Control Sciences
Volume 22(LVIII), 2012
No. 4, *pages 417–425*

Analysis of the job shop system with transport and setup times in deadlock-free operating conditions

JOLANTA KRYSTEK and MAREK KOZIK

This paper presents a generalized job-shop problem taking into consideration transport time between workstations and setups machines in deadlock-free operating conditions. The automated transportation system, employing a number of automated guided vehicles is considered. The completion time of all jobs was applied as the optimization criterion. The created computational application was used to solve this problem in which chosen priority algorithms (FIFO, LIFO, LPT, SPT, EDD and LWR) were implemented. Various criteria were used to assess the quality of created schedules. Numerical results of the comparative research were presented for various criteria and rules of the priority.

Key words: job shop, production schedule, transport, setup time, dispatch rules, deadlock

1. Introduction

Job-shop problem is commonly considered a particularly difficult issue of combinatorial optimization. Because of very big practical significance, the problem with purpose criterion which is the completion time of all tasks has been thoroughly analyzed by many researchers and many accurate as well as approximate algorithms have been developed.

Job shop problem can be summarized as follows: a collection of jobs and collection of machines are given. Each job has to be processed by a number of machines in a given order and there is no recirculation. Each job is a series of operations (tasks) which have to be performed in a sequence, without interruptions, by a machine assigned for each operation (task) within a determined amount of time. For each task execution time is specified, which is usually part of the time needed to prepare a workstation to perform a given task, and the time to restore it to its original state. It also often includes transport time to the generated object position. At any moment the machine can be performing up to one operation. The objective is to minimize the makespan C_{max}. This problem consists of establishing a schedule (assignment of consecutive tasks to proper machines within a

The authors are with Department of Automatic Control, Silesian University of Technology, Gliwice, Poland. E-mails: jolanta.krystek@polsl.pl, marek@kozik.eu

This work was partly supported by the BK-214/Rau-1/2011. Preliminary version was presented on conference KKAPD 2012.

Received 26.10.2012.

determined amount of time) using a chosen priority rule. The problem described above belongs to problem class which are strongly NP-hard and is one of the classic problems of combinatorial optimization.

In classical scheduling problems, decisions on technological tasks and transport tasks are often taken independently or problems are limited only to the technological tasks. This simplification causes the quality of production schedule to be unsatisfactory. In industrial production processes, in many cases, we often encounter situation in which setup time significantly exceeds processing time. Also the number of transport resources is limited which may cause system deadlock.

2. Formulation of the job shop problem with transport and setups

Job shop problem is one of the most classical scheduling problems [2]. This problem is formulated as follows.

Given are m machines $M_1, M_2, ..., M_m$ and r tasks $J_1, J_2, ..., J_r$. The job J_j consists of n_j operations $O_{1j}, O_{2j}, ...,O_{n_j j}$. It is convenient that the following operations for all tasks should be numbered $k = 1,...,N$, where $N = \sum_{j=1}^{n} n_j$. Each operation k has the duration of the $p_k > 0$ and the machine $M(k)$, where the operation is provided. The operation must be carried out on the machine $M(k)$ without the expropriation. We also assume that for two successive operations $k = O_{ij}$ and $s(k) = O_{i+1,j}$, from the same task, the following condition is true:

$$M(k) \neq M(s(k)). \tag{1}$$

Let S_k be the time of the initiation of operation k, then C_k time, described by (2), is the end time of an operation k, and (S_k) sets out a schedule.

$$C_k = S_k + p_k \tag{2}$$

$$S_k + p_k \leqslant S_h \tag{3}$$

$$S_h + p_h \leqslant S_k. \tag{4}$$

Schedule (S_k) is executable if for any two consecutive operations k and $s(k)$, from the same task, condition (2) is satisfied and if for any two operations k and h such that $M(k) = M(h)$ condition (3) or (4) is satisfied. The aim is to find the following schedule that has minimal length of the ordering (called makespan)

$$C_{max} = \max C_k \quad \text{for} \quad k = 1,...,N, \quad \text{where} \quad N = \sum_{j=1}^{n} n_j. \tag{5}$$

Consideration of inter-machine transport and machine setups significantly increases the complexity of calculation algorithms. Quantity of transport resources (e.g. AGV - Automated Guided Vehicles) is most often limited, which considerably affects the final alignment. This is because the tasks are not always performed immediately one after another. Time of transport between the machines is usually greater than zero and may cause occurrences of "gaps" in the final alignment.

Transport operation usually consists of [5]:

- choosing transport resource and assigning it to specified transport operation,
- picking a pallet with detail from initial machine buffer,
- transporting the pallet between the machines in a specified time,
- placing the pallet with detail in initial buffer of consecutive production machine in accordance with the applied technological order.

Transport times between specified resources result, among others, from the distance between the specific resources.

In the situation where the number of transport machines (trucks, robots or other transport machines) is much smaller than the number of tasks (in extreme case equal to one), occurrence of the so called "transport conflicts" is possible. These conflicts occur in individual production phases when the number of tasks that require transport is higher than the number of available transport resources [5].

In the classic problem of job shop, setup did not occur openly or it was assumed that setup times equal zero. Setup is the process of changing equipment machines in the exercise task. The most general case assumes that setup time depends on the machine and on the order of tasks that are being performed. Setup times can be different for each type of operation which will be performed by the machine. This implicates the necessity to introduce setup times between individual machine tooling, which in consequence allows very precise establishment of production schedule. It is possible that machine setup time for a given job from task A to other job to task B can be different than time required for setup of machine "the other way around".

3. Implemented priority rules

Because of NP-hardness of the considered problem, priority algorithms were used to solve it. They are single-phase algorithms, which characterize in high speed of generating production schedule, but unfortunately sometimes at the cost of quality of obtained solutions.

Six rules of priority-based assignment of jobs for job-shop system were chosen for implementation [6]:

1. FIFO (First In First Out) - the job which will be first in line for the machine will be done first,
2. LIFO (Last In - First Out) - the job which will be last in line for the machine will be done first,

3. SPT (Shortest Processing Time) - jobs are assigned to machines in accordance with non-decreasing processing times,

4. LPT (Longest Processing Time) - jobs are assigned to machines in accordance with decreasing processing times,

5. LWR (Least Work Remaining) - jobs are assigned to machines in accordance with the increasing sums of processing times for tasks remaining to be completed within the jobs,

6. EDD (Earliest Due Date) - jobs are assigned to machines in accordance with non-decreasing required earliest times for jobs completion.

In each algorithm, the jobs are put in order according to established priority rule. Next, from list formed in such manner, the tasks are assigned to machines in the moments of their release from the previous task. Deciding upon the sequence of production jobs performance is one of the alignment problems. Such decisions are made during running assignment of jobs to machines which will perform them. Each decision regarding choice of job (from the collection awaiting to be planned to perform) regardless of the applied criterion, is giving that job a priority. Planning of stands workloads (scheduling) consists exclusively of more or less conscious successive prioritizing of jobs. According to exclusion principle, job queues create before the machines and it must be decided which job should be performed first.

4. Simulation experiments

Example 1

For production system consisting of 4 production resources $(M1 \div M4)$, 5 jobs in which maximum number of tasks is 4 and possessing three transport resources, the input data is presented in Tab. 1. Setup time are fixed and equals 10 time units.

Table 4. Input data for example 1.

Job	Routes / (processing time) (p_{ij})				Release date (r_{ij})	Due date (d_j)
1	M1/(10)	M2/(20)	M3/(25)	-	10	100
2	M2/(25)	M1/(20)	M5/(10)	M4/(15)	5	100
3	M2/(10)	M4/(10)	-	-	20	100
4	M1/(15)	M3/(10)	M4/(20)	-	5	100
5	M3/(10)	M5/(15)	-	-	10	100

Figures 1–6 show the production schedules depending on the chosen priority rule.

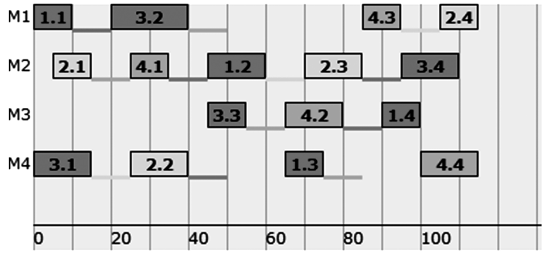

Figure 1. Machines work schedule for the FIFO rule.

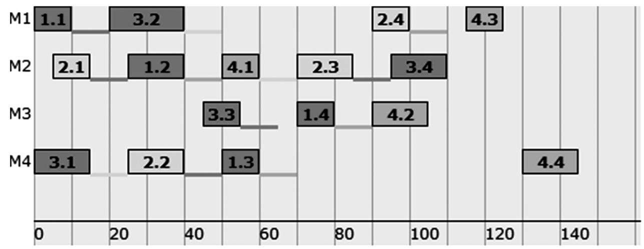

Figure 2. Machines work schedule for the LIFO rule.

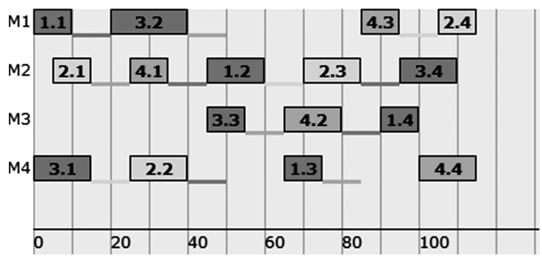

Figure 3. Machines work schedule for the SPT rule.

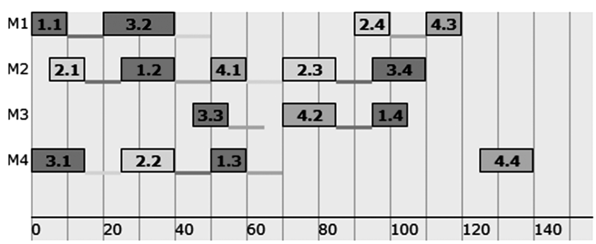

Figure 4. Machines work schedule for the LPT rule.

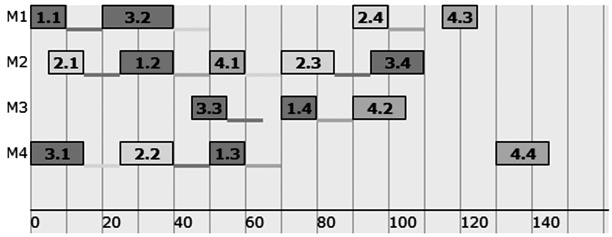

Figure 5. Machines work schedule for the LWR rule.

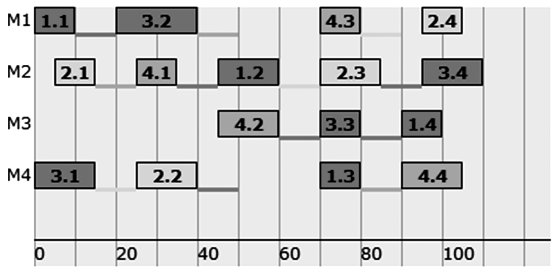

Figure 6. Machines work schedule for the EDD rule.

Table 5. Results.

	Dispatch rules					
	FIFO	LIFO	SPT	LPT	LWR	EDD
C_{max}	115	145	115	140	145	110

Completion time of all jobs depending on used dispatch rules are depicted in Tab. 2.

Example 2

Production system consists of 4 machines (data given in Tab. 3, diagram in Fig. 7). In this system, 4 different jobs have to be executed, whereas not all tasks of individual jobs will be performed by all machines. Number of tasks within a job does not exceed 4 which implicates that maximum route length equals 4. In the described production system, 1 transport resource is available. Times of transport between the machines are fixed and equal to 10 time units. The purpose of the example is to present a situation in which a system deadlock occurred.

The tasks were aligned in accordance with FIFO rule (transport and setup times were not considered). The result of the alignment is presented in Fig. 8.

It can be observed that tasks 1.1 and 2.1 were completed in the same moment and must be transported to opposite workstations. This subsystem (two resources M_1, M_2 and

Table 6. Input data for example 2.

Job	Routes / (processing time) (p_{ij})				Release date (r_{ij})
1	M1/(10)	M2/(20)	M3/(35)	-	0
2	M2/(10)	M1/(20)	M5/(30)	M4/(15)	0
3	M2/(10)	M4/(10)	-	-	20
4	M1/(15)	M3/(10)	M4/(20)	-	30

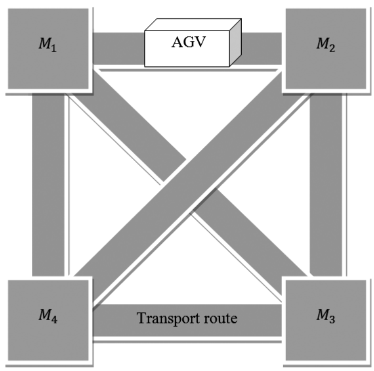

Figure 7. Production system diagram.

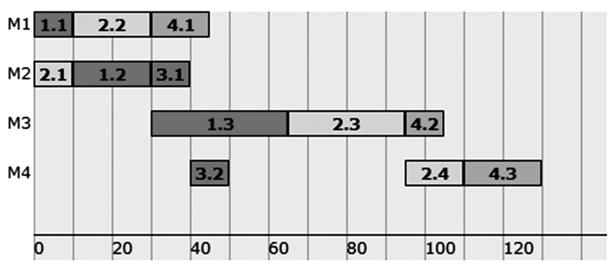

Figure 8. Machine work schedule with occurring deadlock.

AGV) is presented in Fig. 9. Both resources demand access to the vehicle at the same time $t = 0$. Because of the AGV available for this route will be called by both resources simultaneously, therefore a conflict situation will occur – system deadlock.

In the described example, the problem of deadlock occurrence may be easily solved by applying priority rule. Assume that the transport time between the resources equals

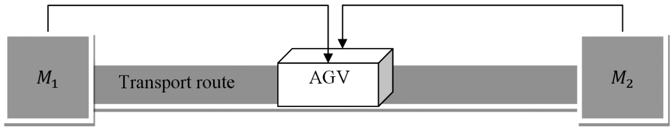

Figure 9. Production system diagram.

to 10 time units. If this rule is accounted for the lowest resource number, the production schedule would be as presented in Fig. 10 and 11.

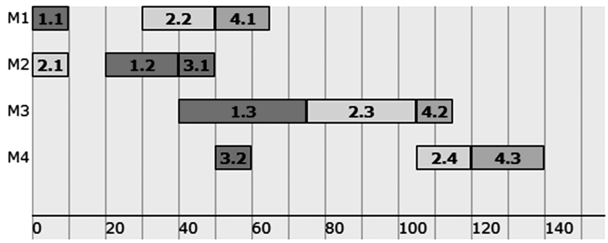

Figure 10. Production system diagram.

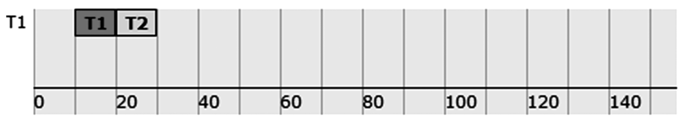

Figure 11. Machines work schedule without deadlock.

By modifying the above example with machines setup time M_1 and M_2 for the jobs Z_1 and Z_2 (25 unit), with the assumption that setup of the machine takes place after delivering the job by a transport resource, the schedule is as shown in Fig. 12.

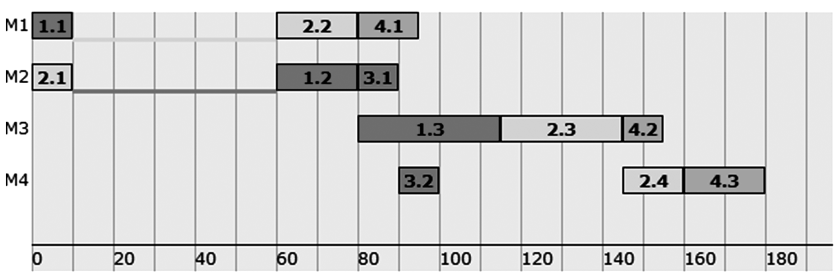

Figure 12. Machine work schedule accounting for machines setup.

5. Conclusions

In conclusion one can highlight, that in order to guarantee a deadlock-free operation, one of the following strategies can be applied:

1. deadlock protection – there are two possibilities for deadlock protection:
    - all resources necessary to complete a given process may be assigned to this process before proceeding to its execution,
    - optionally: establishing an order in which requests for specific resources must occur,
2. deadlock avoidance - system is checked, whether its status after execution of the processes is deadlock-free,
3. locating and eliminating deadlocks - system is periodically controlled in order to find out, whether a deadlock occurs.

References

[1] Z. BANASZAK and L. JAMPOLSKI: Computer Aided Modeling of the Flexible Production Systems. WNT, Warszawa, 1991, (in Polish).

[2] P. BRUCKER: The Job-Shop Problem: Old and New Challenges. *In Proc. of the 3rd Multidisciplinary Int. Conf. on Scheduling: Theory and Applications (MISTA)*, Paris, France, (2007), 15-22.

[3] D. KRENCZYK and A. DOBRZA NSKA-DANIKIEWICZ: The deadlock protection method used in the productions systems. *J. of Materials Processing Technology*, **164-165** (2005), 1388-1394.

[4] J. KRYSTEK and M. KOZIK: Analysis of the job shop system with transport and setup times. *Automatyka AGH*, **13**(2), Krakow, (2009) 391-400, (in Polish).

[5] C. SMUTNICKI and A. TY NSKI: Simultaneous machine scheduling and AGV route planning in the FMS. *Proc. of the 11th IEEE Int. Conf. on Methods and Models in Automation and Robotics*. (2005), 1131-1136.

[6] S. PANWALKAR and W. ISKANDER: A Survey of Scheduling Rules. *Operations Research*, **25**(1), (1977), 45-61.