БЪЛГАРСКА АКАДЕМИЯ НА НАУКИТЕ • BULGARIAN ACADEMY OF SCIENCES

ПРОБЛЕМИ НА ТЕХНИЧЕСКАТА КИБЕРНЕТИКА И РОБОТИКАТА, **66**
PROBLEMS OF ENGINEERING CYBERNETICS AND ROBOTICS, **66**

София • 2015 • Sofia

Optimal Planning of the Production of Corpus Details on Metal Cutting Machines with the Help of Computer Numeric Control

Chavdar Korsemov, Hristo Toshev

Institute of Information and Communication Technologies 1113 Sofia

Emails: ***chkorsemov@iinf.bas.bg***, ***hr_toshev@mail.bg***

Abstract: *The optimal planning of details mechanical processing is a key problem, directly affecting the productivity and efficiency of the activity of a machine building company. The combinatorial character of the problems, connected with schedules creating, requires the formulation and solution of a corresponding optimization problem. The paper considers the problem of defining the optimal time sharing of corpus details processing for M500 metal processing machine. Some optimization problems, corresponding to two technologic processing sequences, have been formulated and solved in the paper presented. The results of the digital experiments are shown and the corresponding production schedules are presented.*

Keywords: *Production scheduling, linear programming optimization, CNC metalworking machines.*

1. Introduction

The production activities are complex, dynamic, stochastic systems. Since the beginning of the organized production, the workers, engineers and managers have developed very intelligent and practical ways to control the production activity. Many manufacturers generate and update the production schedules that perform the plans determining when to execute given controllable activities. The production schedules coordinate the activities with the purpose to increase the productivity and to minimize the operational expenses. The production schedule may identify any conflicts in the resources, control the start of given activities in the production department, ensure on-time orders of the necessary raw materials, determine whether the requirements for the terms are met and identify the time periods for preventive support.

Two key problems in production planning are “priority” and “capacity”. In other words, “What is to be accomplished first” and “Who must do it?” questions. *Graphics* is defined as “determining the time of execution of a given problem” and it is noticed that there are several types of planning in the production companies, including the determination of a detailed schedule that shows when a given operation must be started and finished. *Detailed planning* is defined as “current determination of the dates for starting and completion of operations or groups of operations, so that to point out when they have to be executed, in order to keep to the production order”. This is familiar as *planning of operations, planning of the order or creating a production schedule*. The present paper deals with this sort of planning.

Unfortunately, many manufacturers have non-efficient production schedules. They produce articles and provide them to their clients, but use incorrect collection of independent schedules that are often ignored, organize periodic meetings, where irrelevant information is shared, include expeditors, that come from one crisis into another, and ad-hoc decisions made by persons, who cannot observe the whole system. The systems of production planning rely on decision makers, but many of them need help in working out plans under real conditions.

The computerized schedules design might help the manufacturers improve their everyday work, respond quickly to the users’ requests and create realistic plans, but their success requires the use of techniques, accounting the constraints and their integration with other production planning systems [1, 2, 3, 4]. These schedules use the conditions in a production workshop, as well as the requirements towards already produced orders. Nevertheless, only 25 % of the companies have used planning with constraints for a part or for all of their operations. The integration is also difficult. Just 48 % of the companies have declared that the computer planning system has received data automatically by other systems, 30 % have answered, that a great part of the data are manually entered and 21 % – that all the data are manually entered.

2. Problem formulation

The control of the production process includes all the activities that have to be realized, in order to plan correctly the resources distribution and achieve its purposes. This includes information usage of the time duration of the production process, the time duration of the separate operations, the available production resources (machines, specialists, materials), the existing constraints, etc. [5, 6, 7, 8, 9, 10]. This information is used in order to define the time moments of starting and completing of every operation, the sequence of operations, the routes of the details among the processing machines, i.e., to prepare a production plan, subject to all the requirements and constraints.

Table 1

No	Detail name	Materaial	Technologic operations	Time, hours	Machine
1	Basis	Cast	cutter 1	8	Coord. Mach. Mikromat
			drilling-cutting 1	6	Coord. Mach. VTEC
			drilling	6	Borverg with CNC MicroCUT
2	Column	Cast	cutter 1	8	Coord. Mach. Mikromat
			drilling-cutting 1	10	Coord. Mach. VTEC
			drilling	6	Borverg with CNC MicroCUT
3	Frog	Cast	cutter 1	8	Coord. Mach. Mikromat
			cutter 2	8	Horizontal cutter with CNC
			drilling-cutting 1	8	Coord. Mach. VTEC
			drilling	4	Borverg with CNC MicroCUT
4	Sledge on Z	Cast	drilling-cutting 3	4	Coord. Mach. Mikromat
			cutter 3	1	Coord. Mach. VTEC
			drilling-cutting 2	2	Horizontal cutter with CNC
5	Mass	Cast	cutter 1	4	Coord. Mach. Mikromat
			drilling-cutting 1	12	Coord. Mach. VTEC
			drilling-cutting 2	4	Horizontal cutter with CNC
			polishing	8	Sclaifhobel
6	Mandril box	Cast	drilling-cutting 3	6	Coord. Mach. Mikromat
			drilling-cutting 2	8	Horizontal cutter with CNC
7	Shop V-shaped	Cast	cutter 2	6	Horizontal cutter with CNC
			drilling-cutting 4	8	Borverg with CNC MicroCUT

It is desirable that this production plan will be the best possible (optimal) with respect to certain criteria. The development of modern computer techniques and the scientific achievements in operation research field have enabled the use of efficient mathematical tools and methods in reaching the purpose above described [6, 8, 11, 12, 13]. The paper presents the results of the optimal schedule of mechanic processing of corpus details on M500B metal processing machine.

3. Description of the problems in the production of metal cutting and metal processing machines with the help of a Digital Processing Device (DPD)

In the company production on metal cutting and metal processing machines with DPD, one of the most important and crucial moments, referring to the purposes planned, is connected with processing of the corpus details. These details are seven, they present large size casts with weight up to several hundred kilograms, used in the production of all machines with DPD. Each one of them is ordered in specialized casting companies that are outside the company-manufacturer.

Table 2

Machine No	Machines	Operations	Operation No
1	Coord. Mach. Micromat	Cutter 1 Drilling-cutting 3	1 2
2	Coord. Mach. VTEC	Drilling-cutting 1 Cutter 3	3 4
3	Horizontal cutter with CNC	Cutter 2 Drilling-cutting 2	5 6
4	Borverg with CNC MicroCUT	Drilling Drilling-cutting 4	7 8
5	Schlaifhobel	Polishing	9

Before being used in machine mounting, the corpus details must be processed respectively. According to the technological plan, shown in Table 1, these processing manipulations require nine operations totally and are executed on five types of machines, indicated in Table 2.

The main problems, connected with corpus details processing, are as follows:

- Since they are ordered for casting in other companies, it is necessary to determine the moment of their delivery. Their early delivery leads to overloading of the store areas and freezing of the financial resources. Their late delivery causes a delay in machines mounting and respective financial penalties.

- The determination of the delivery time moments must be connected with the schedule of their processing. Since most of the details are on one and the same machines, and the corresponding operations have different duration, the processing schedule must consider this.
- There exists also a technological sequence of details processing, as shown in Table 1 and the production must be coordinated with it as well.
- The machines used for processing given in Table 2, must be completely loaded and thus minimize their non-production time.
- The corpus details are significant and expensive details and the non-efficient organization of their processing causes non-efficiency that makes the production of metal cutting and metal processing machines with the help of DPD in "RAIS" company expensive.

The problems above described can be solved controlling the production process using efficient and optimal production schedules of corpus details processing.

4. Formulation of an optimization problem for mechanical processing of corpus details on M500 machine

Every corpus detail passes a given number of operations with a certain sequence and duration (Table 1). It is necessary to determine the minimal total time of processing of all details, the initial time moments of starting and completing of each operation, as well as the minimal possible total duration of the whole process. For this purpose a linear programming optimization problem is formulated and solved.

Using Table 1, Table 2 and the denotations introduced:

- X_{1E}, X_{2E}, X_{3E}, X_{4E}, X_{5E}, X_{6E}, X_{7E} – time moments of completion of the processing of details from 1 up to 7;
- X_{11}, X_{12}, X_{14}, – time moments of beginning of the processing of detail 1 on machines 1, 2 and 4 respectively;
- X_{21}, X_{22}, X_{24}, – time moments of beginning of the processing of detail 2 on machines 1, 2 and 4 respectively;
- X_{31}, X_{33}, X_{32}, X_{34}, – time moments of beginning of the processing of detail 3 on machines 1, 3q 2 and 4 respectively;
- X_{41}, X_{42}, X_{43} – time moments of beginning of the processing of detail 4 on machines 1, 2 and 3 respectively;
- X_{51}, X_{52}, X_{53}, X_{55} – time moments of beginning of the processing of detail 5 on machines 1, 2, 3 and 5 respectively;
- X_{61}, X_{63} – time moments of beginning of the processing of detail 6 on machines 1 and 3 respectively;
- X_{73}, X_{74} – time moments of beginning of the processing of detail 7 on machines 3 and 4 respectively;

The following linear programming optimization is formulated:

(1) $\min (X_{1E}+X_{2E}+X_{3E}+X_{4E}+X_{5E}+X_{6E}+X_{7E})$,

under constrains, presenting the sequence of processing operations, i.e., the dependences of each subsequent operation on the duration of the preceding one:

(2) $X_{12} - X_{11} \geq 8$ – for detail 1 on machine 2,
(3) $X_{14} - X_{12} \geq 6$ – for detail 1 on machine 4,
(4) $X_{1E} - X_{14} \geq 6$ – end of the processing of detail 1,
(5) $X_{22} - X_{21} \geq 8$ – for detail 2 on machine 2,
(6) $X_{24} - X_{22} \geq 10$ – for detail 2 on machine 4,
(7) $X_{2E} - X_{24} \geq 6$ – end of the processing of detail 2,
(8) $X_{33} - X_{31} \geq 8$ – for detail 3 on machine 3,
(9) $X_{32} - X_{33} \geq 8$ – for detail 3 on machine 3,
(10) $X_{34} - X_{32} \geq 8$ – for detail 3 on machine 4,
(11) $X_{3E} - X_{34} \geq 4$ – end of the processing of detail 3,
(12) $X_{42} - X_{41} \geq 4$ – for detail 4 on machine 4,
(13) $X_{43} - X_{42} \geq 1$ – for detail 4 on machine 3,
(14) $X_{4E} - X_{43} \geq 2$ – end of the processing of detail 4,
(15) $X_{52} - X_{51} \geq 4$ – for detail 5 on machine 2,
(16) $X_{53} - X_{52} \geq 12$ – for detail 5 on machine 3,
(17) $X_{55} - X_{53} \geq 4$ – for detail 5 on machine 5,
(18) $X_{5E} - X_{55} \geq 8$ – end of the processing of detail 5,
(19) $X_{63} - X_{61} \geq 6$ – for detail 6 on machine 3,
(20) $X_{6E} - X_{63} \geq 8$ – end of the processing of detail 6,
(21) $X_{74} - X_{73} \geq 6$ – for detail 7 on machine 4,
(22) $X_{7E} - X_{74} \geq 8$ – end of the processing of detail 7,

and constraints, presenting the machines occupancy in a given sequence of processing of several details (according to Table 1) on one and the same machine:

(23) $X_{21} - X_{11} \geq 8$ – detail 2 waits for detail 1 on machine 1,
(24) $X_{31} - X_{21} \geq 8$ – detail 3 waits for detail 2 on machine1,
(25) $X_{41} - X_{31} \geq 8$ – detail 4 waits for detail 3 on machine 1,
(26) $X_{51} - X_{41} \geq 4$ – detail 5 waits for detail 4 on machine 1,
(27) $X_{61} - X_{51} \geq 4$ – detail 6 waits for detail 5 on machine 1,
(28) $X_{22} - X_{12} \geq 6$ – detail 2 waits for detail 1 on machine,

(29) $X_{32} - X_{22} \geq 10$ – detail 3 waits for detail 2 on machine 2,

(30) $X_{42} - X_{32} \geq 8$ – detail 4 waits for detail 3 on machine 2,

(31) $X_{52} - X_{42} \geq 1$ – detail 5 waits for detail 4 on machine 2,

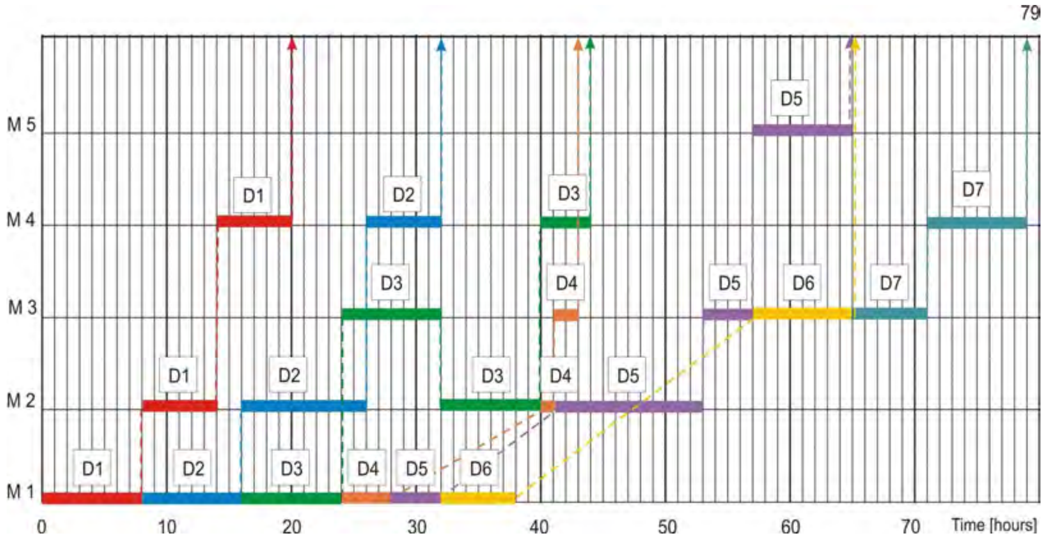

Fig. 1. Solution of problem 1
Time scheduling of the details processed in a sequence:
D1, D2, D3, D4, D5, D6, D7

(32) $X_{43} - X_{33} \geq 8$ – detail 4 waits for detail 3 on machine 3,

(33) $X_{53} - X_{43} \geq 2$ – detail 5 waits for detail 4 on machine 3,

(34) $X_{63} - X_{53} \geq 4$ – detail 6 waits for detail 5 on machine 3,

(35) $X_{73} - X_{63} \geq 8$ – detail 7 waits for detail 6 on machine 3,

(36) $X_{24} - X_{14} \geq 6$ – detail 2 waits for detail 1 on machine 4,

(37) $X_{34} - X_{24} \geq 6$ – detail 3 waits for detail 2 on machine 4,

(38) $X_{74} - X_{34} \geq 4$ – detail 7 waits for detail 3 on machine 4.

The total duration of processing of all corpus details *T* can be computed, subtracting from the time of completion of the last detail, the initial time of processing of the first detail, i.e.:

(39) $$T = \max (X_{iE}) - \min (X_{i1}), \text{ for } i=1, \dots , 7.$$

The linear optimization problem thus formulated could be solved using any of the software systems, applied in the solution of such problems. In this case LINGO software program of LINDO Ltd company is used. Having in mind that the final purpose is obtaining the respective production schedule, it is appropriate to present the problem solution graphically.

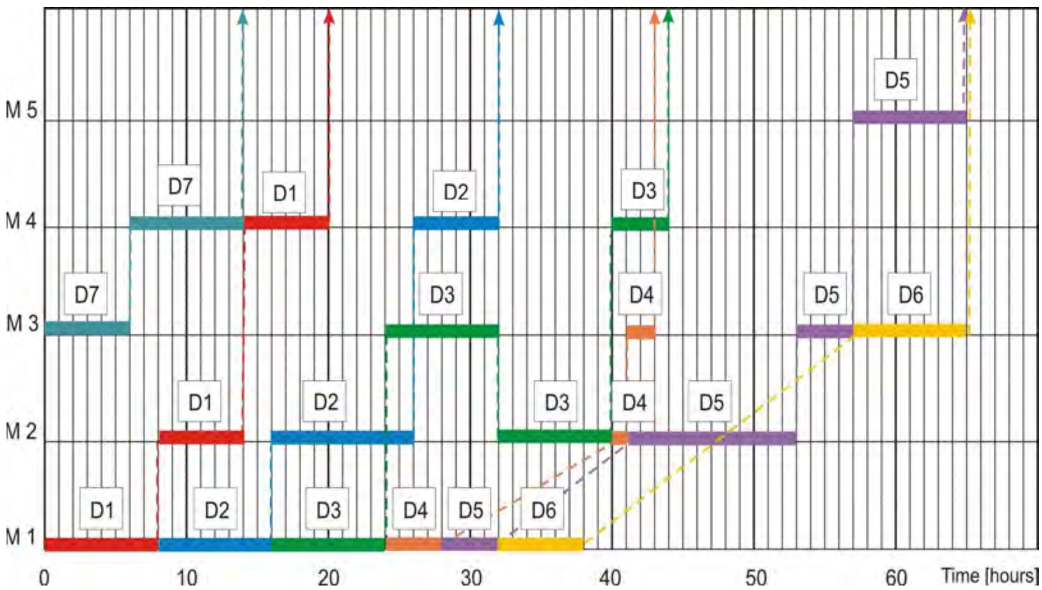

Fig. 2. Solution of problem 1a

Scheduling of the details processed in a sequence:
D1 and D7, D2, D3, D4, D5, D6

The graphic presentation of the solution obtained is shown in Fig. 1.
It can be seen from the solution of problem 1 that the total time of completion of the processing of the corpus details is *T* = 79 hours.
According to the technological plan from Table 1, detail 7 must wait for the end of processing detail 6 on machine 3 and of detail 3 on machine 4. After analysis of the solution obtained it could be noticed that since the first processing of detail 7 is on machine 3, which is free up to the time when detail 3 does not complete the preceding processes, it is possible that detail 7 will not to be limited by the processing of details 3 and 6. This leads to transformation of problem 1 into problem 1a, removing constraints (35) and (38). The graphic presentation of the solution of problem 1a is shown in Fig. 2.

As seen from the solution obtained, this modification of the initial problem leads to decrease of the total time of process completion when working on corpus details up to T = 65 hours.

4. Conclusion

In the current practice of the company, the corpus details processing is accomplished subsequently, every following detail waiting for the completion of the processing of the former detail (according to Table 1) and it takes totally about 135 hours. Solving the formulated optimization problem 1, this time is decreased to 79 hours. The modification of problem 1 into problem 1a, that allows simultaneous processing of detail 1 and detail 7 leads to the decrease of the total time of processing from 79 up to 65 hours.

Having in mind the present status of the corpus details preparation, and the results from the solutions of the formulated optimization problems, it could be concluded that the approach used is appropriate and efficient. The application of the determined production schedules in the practice of the machine building company will determine the direction of the future investigations in improvement of the optimization approach being developed.

References

1. Borissova D., I. Mustakerov. Open job shop scheduling via enumerative combinatorics. Int. Journal of Mathematical Models and Methods in Applied Sciences, ISSN: 1998-0140, Vol. 9, 2015, pp. 120-127, **http://www.naun.org/main/NAUN/ijmmas/2015/a282001-033.pdf**
2. Scholz-Reiter B, Rekersbrink H, Goerges M (2010) Dynamic Flexible Flow Shop Problems—Scheduling Heuristics vs. Autonomous Control. CIRP Annals-Manufacturing Technology 59(1):465–468
3. Nonaka Y, Erdos G, Kis T, Nakano T, Vancza J (2012) Scheduling with Alternative Routings in CNC Workshops. CIRP Annals-Manufacturing Technology
4. Liu, L. L., Zhao, G. P., Ou´Yang, S. S., & Yang, Y. J. (2011). Integrating theory of constraints and particle swarm optimization in order planning and scheduling for machine tool production. *International Journal of Advanced Manufacturing Technolog y*, 57 (1-4), 285-296. **http://dx.doi.org/10.1007/s00170-011-3294-6**
5. Akturk M. Selim and Serkan Ozkan, *Integrated scheduling and tool management in flexible manufacturing systems***,** International Journal of Production Research, vol. 39, No 12, 2001, 2697-2722.E m e l y a n o v, V. V., V. M. K u r e y c h I k, V. V. K u r e y c h I k, *Theory and Practice of Evolutionary Modelling*, Moscow, 2003, (in Russian).
6. Graham, R. L., Lawler, E. L., Lenstra, J. K., and Rinnooy Kan, A. H. G. *Optimization and approximation in deterministic sequencing and scheduling: a survey. Annals of Operations Research*, 1979, 5:187–326.
7. Morton, T. E. and Pentico, D. W. *Heuristic Scheduling Systems with Applications to Production Systems and Project Management*. Wiley, New York, 1993.
8. Pinedo, M. *Scheduling: Theory, Algorithms, and Systems.* Prentice Hall, 2002, 2nd edition.
9. Horn, S., Weigert, G., Beier, E. , *Heuristic optimization strategies for scheduling of manufacturing processes*, Electronics Technology, 2006. ISSE '06. 29th International Spring Seminar on, 2006, 422-427.

10. Mustakerov I., D. Borissova, *Technical systems design by combinatorial optimization choice of elements on the example of night vision devices design*, Comptes rendus de l'Academie bulgare des Sciences, Tom 60, No 4, 2007, 373-380.
11. Borissova D., I. Mustakerov. A parallel algorithm for optimal job shop scheduling of semi-constrained details processing on multiple machines. In Proc. Advanced Information Science and Applications – Volume I, 18th Int. Conf. on Circuits, Systems, Communications and Computers (CSCC 2014), July 17-21, 2014, Santorini Island, Greece, ISBN: 978-1-61804-236-1, pp. 145-150, **http://www.ips.iit.bas.bg/I_Mustakerov/Pcroc_AdvancesInfSci&Apps_145_150.pdf**
12. Zhang, R., S. Song, C. Wu, A two-stage hybrid particle swarm optimization algorithm for the stochastic job shop scheduling problem, Knowledge-Based Systems 27 (2012) 393–400
13. Pezzella, F., G. Morganti, G. Ciaschetti, A genetic algorithm for the flexible jobshop scheduling problem, Computers and Operations Research 35 (10) (2008) 3202–3212

Оптимальное планирование производства корпусных деталей для металлорежущих машин с цифровым програмным управлением

Чавдар Корсемов, *Христо Тошев*

Институт информационных и коммуникационных технологий, 1113 Sofia

Emails: ***chkorsemov@iinf.bas.bg***, ***hr_toshev@mail.bg***

Р е з ю м е

Оптимальное планирование механической обработки деталей является главной проблемой, директно влияющей на производительность и эффективность деятельности машиностроительной фирмы. Комбинаторный характерь проблемм, связанных с определением разписаний, требует формулировки и решения соответствующих оптимизационных задач. В статье рассматривается проблемма определения оптимального разписания механической обработки корпусных деталей для металлообрабатывающей машины М500. Формулированы и решены оптимизационные задачи, соответствующие двумя технологическим последовательностям обработки. Показаны результаты цифровых экспериментов, также как и полученные производственные разписания.