Proceedings of the 15th International Conference on Manufacturing Systems – ICMaS
Published by Editura Academiei Române, ISSN 1842-3183

"Politehnica" University of Bucharest, Machine and Manufacturing Systems Department
Bucharest, Romania, 26–27 October, 2006

A NEW VIEW ON SEQUENCING THE ACTIVITIES OF PRODUCTION PROJECTS

Corneliu NEAGU, Mădălin Gabriel CATANĂ, Maria Magdalena ROŞU, Lucia Violeta MELNIC

Abstract: *This paper quantitatively debates some sequencing types, rules, and scenarios for scheduling the activities of the production projects. An ample and up-to-date documentation and the authors' experience in the project-scheduling field are supporting the study. Despite the enormous work that has been done in this management area, the authors consider that their approach is highly important for the systematization, quantification, and proper utilization of fundamental knowledge in the scheduling field.*

Key words: *scheduling, sequencing rules and scenarios, sequencing list of activities, resources load reports, projects' schedules.*

1. INTRODUCTION

Scheduling generally comprises a number of managerial activities for establishing the timing (in hours, days, weeks, etc.) of production tasks on the manufacturing resources of the firm (job shops, flow shops, banks of parallel machines, single machines, etc.). This is the common view of many reference works [3, 7, 8, 9, 11–18].

Moreover, scheduling is seen as one of the most important links in the production planning and control chain because its main goal is to optimally manage the queue length at the bottleneck work centers so as to meet all the activities due dates with minimum levels of work in process (WIP). To manage the queues at work centers, sequencing rules for production activities are commonly used. Despite the huge number of sequencing rules that are advocated in the literature, only few of them are widely used in practice. A selection of the most important rules [1, 2, 4–6, 10] is as follows:

a) *Slack Time Rule*: the smaller is total slack (*mT*) of the task the greater will be the priority to schedule this task. Total slack (*mT*) is computed as follows:

$$mT = T_f - T_c - T_s \,. \tag{1}$$

where: T_f is the project's due date; T_c – current time; T_s – sum of processing times of remaining activities.

b) *Critical Ratio Rule*: the lesser is critical ratio (*RC*) of the activity the greater will *be* the priority to schedule this activity. Critical ratio (*RC*) is expressed as follows:

$$RC = \frac{mT}{T_f - T_o} \,. \tag{2}$$

where T_o is the start time of the analyzed activity.

If $RC < 0$, the production project is behind schedule.

c) *Processing Time Rule*: the shorter is the processing time of a job the bigger will be the priority to schedule that job. This rule is usually suiTable for reducing the flow times and the delays of production projects.

d) *Due Date Rule*: the job with the earliest due *date* is to be given priority for scheduling.

e) *Queuing Limit Rule*: the job that spends in the queue a time longer than a predefined *limit* is to be given priority for scheduling.

All the mentioned sequencing rules rank the individual activities of the projects that share some limited resources of the firm during the same production period. Whatever their ranking, concurrent tasks should be overlapped if do not overload the common resources.

Moreover, some of the presented rules may give rise to abnormal results for specific projects. To demonstrate this, let us consider a simple production project that is described by the network model in Fig. 1.

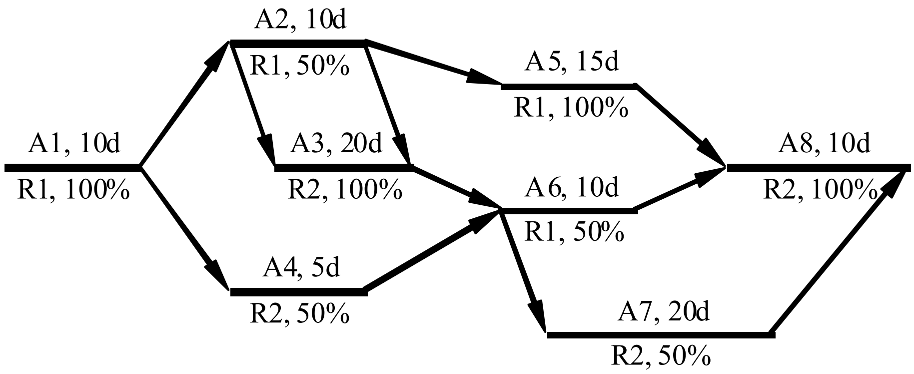

Fig. 1. Network model of a simple project.

In the example project, A3 represents an activity with a 20 days long planned processing time on resource R2. If equation (1) is used for computing the total slack (*mT*) of activity A3, a negative value is obtained, as follows:

$$mT(A3) = 50 - 10 - (20 + 5 + 20 + 10) = -15\ days,$$

where the project's due date is 50 days after its start and the current time is the earliest start date of activity A3 (10 days after the project starts).

This result is misleading, knowing that negative slacks generally denote tardy projects. This fact can also be derived from equation (2), where critical ratio (*RC*) takes negative values only for negative values of total slack (*mT*).

Finally, it can also be noticed that the last sequencing rule concerning the queuing time limit is not quantified in any way in the literature.

2. ANOTHER APPROACH TO SEQUENCING

The new view on sequencing is primarily founded on the authors' experience in managing production projects, by contract or academically.

Many similarities were observed between PERT-load scheduling models with limited resources and sequencing models. These similarities come from the simple fact that both models permit the construction of resource-constrained load reports and schedules for production projects.

To apply a sequencing model for scheduling the tasks of a production project, the following elements have to be established: available capacity profiles for all the resources that are committed to complete the project; the type of the sequencing model to be used; the sequencing rules and the resulting scheduling scenarios for the project's activities.

Available capacity profiles of the resources are created identically to PERT-load model's case.

There are two types of activities sequencing that may be applied: a FORWARD sequencing that gives rise to early start schedules, or a BACKWARD sequencing that results in late start (and finish) schedules.

The construction of resources load reports depends on the sequencing type, as follows: in FORWARD sequencing, the loads on resources are planned from the project's start date (t_0) to project's due date (t_f), whereas in BACKWARD sequencing an opposite procedure must be followed.

Three steps are to be taken when applying a sequencing model for scheduling the activities of a production project:

- The development of sequencing list that ranks project's activities according to their priority to be scheduled in advance;
- The construction of resources load reports, considering the available capacity profiles of resources and the load (required capacity) of every activity in the sequencing list;
- The construction of the project's schedule, by assigning start and complete times to activities according to their planned loads on resources. A Gantt diagram or a Table representation may be used to depict the schedule.

Different sequencing rules (or sets of rules) that may be used for creating the sequencing list conduct to diverse sequencing scenarios for the production project.

Two types of sequencing scenarios are frequently used in practice: *queue-based sequencing* scenarios and *slack-based sequencing* scenarios. These scenarios will be dealt with in the following.

2.1. Queue-based sequencing

This type of sequencing scenario ranks the activities to be run with a sharable resource according to their arrival in the queue. The highest priority for scheduling is assigned to the first arrivals, by a sequencing rule usually known as *first come – first served* (FCFS) or *first in – first out* (FIFO) rule. However, this rule is ranked third in the set of rules used for building the sequencing list of jobs. The content of the entire set of sequencing rules is as follows:

C1. Network Precedence Rule: in FORWARD sequencing, predecessors outrank their direct or indirect successors on the sequencing list, but in BACKWARD sequencing the successors have priority over their predecessors;

C2. Temporal Constraints Rule: the activities that must be run within some specific and limited time frames due to contractual clauses, lack of necessary resources etc. have priority over the other tasks of the project;

C3. FCFS Rule: in FORWARD sequencing, an earliest start time closer to the project's release date (t_0) gives the job a superior position on the sequencing list, whereas in BACKWARD sequencing a tardier latest finish time of the task (nearer project's due date, t_f) is significant for ranking;

C4. Processing Time Rule: the tasks with shorter run times outrank other activities of the project on the sequencing list.

To apply the above-mentioned rules for developing the sequencing list of activities, a network-planning model of the project must be available. The network model must put in sight all the necessary data about the project's activities, for example: the activities' processing times, relationships, temporal constraints etc. Moreover, in order to make use of rule *C3*, a partial PERT-time calculation has to be done in advance (a forward pass through the network is required for FORWARD sequencing and a backward pass is needed for BACKWARD sequencing).

For example, with no temporal constraints, the activities of the network in Fig. 1 will have the following earliest start times (*es*) in days, relative to the project's start date (t_0): *es*(A1) = 0; *es*(A2) = *es*(A3) = *es*(A4) = 10; *es*(A5) = 20; *es*(A6) = *es*(A7) = 30; *es*(A8) = 40. These values and other necessary data available in Fig. 1 are used to develop the FORWARD sequencing list of activities (see Table 1) and the resulting resources load reports and project schedule in Fig. 2. The capacity available and load on the project's resources (*R*1 and *R*2) are expressed in working days per person (*dp*).

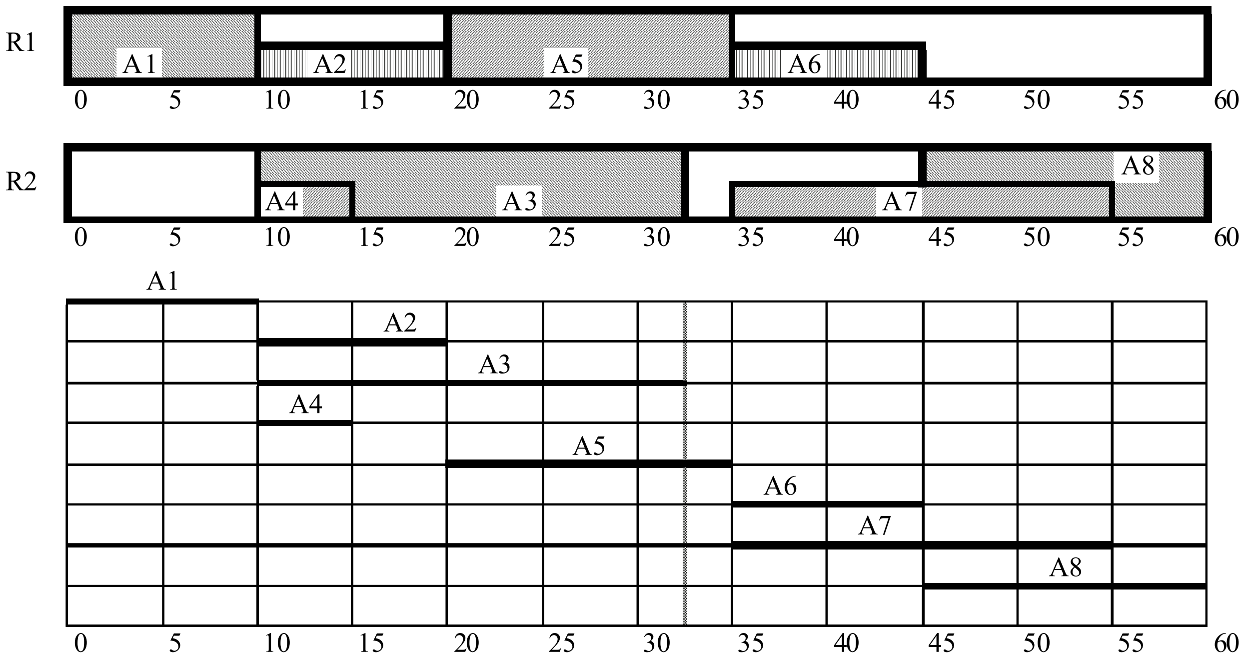

Fig. 2. Resources load reports and project schedule for queue-based FORWARD sequencing.

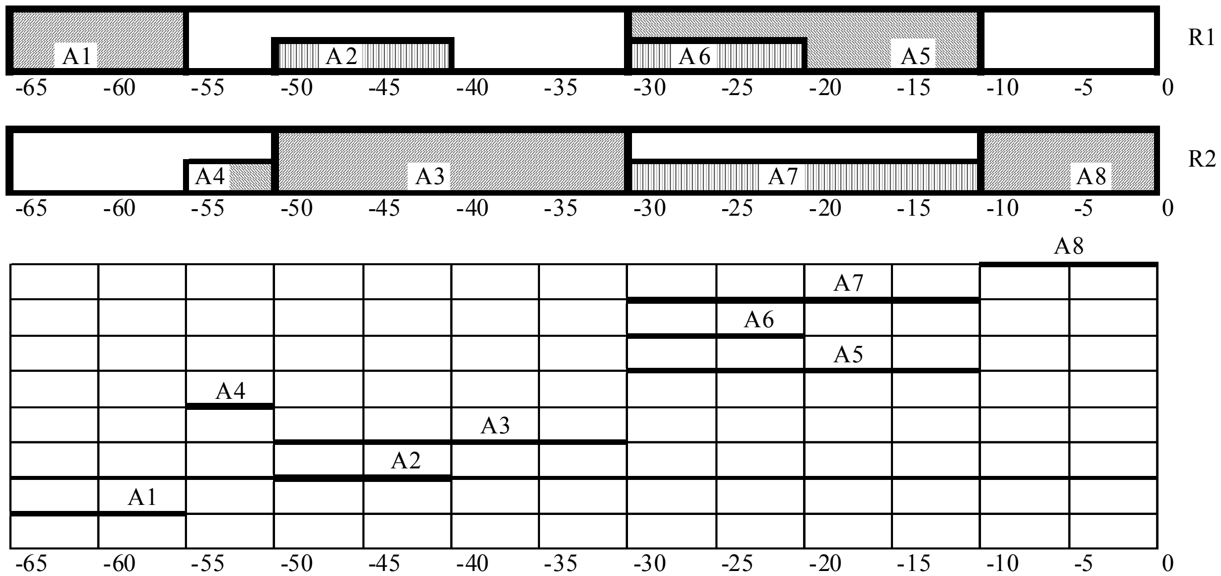

Fig. 3. Resources load reports and project schedule for slack-based BACKWARD sequencing.

2.2. Slack-based sequencing

This sequencing scenario assigns the highest priority for scheduling to the activities with minimum slacks, where the slack of an activity is the difference between the latest and the earliest start times for that activity. To use this *slack time* rule for sequencing the activities of production projects, a complete PERT-time calculation has to be run beforehand. Because slack time rule outranks FCFS rule, the content of the entire set of rules for creating slack-based sequencing lists of jobs becomes as follows:

C1. Network Precedence Rule;

C2. Temporal Constraints Rule;

C3. Slack Time Rule;

C4. FCFS Rule;

C5. Processing Time Rule.

C1, *C2*, *C4*, and *C5* priority rules from above have the same meaning as in section 2.1.

Table 1

Queue-based FORWARD sequencing list of activities

Job	Ranking rule	Resource	Processing time	Resource share	Load
A1	C1	R1	10d	100%	10dp
A4	C4	R2	5d	50%	2,5dp
A2	C1	R1	10d	50%	5dp
A3	C3	R2	20d	100%	20dp
A5	C3	R1	15d	100%	15dp
A6	C1	R1	10d	50%	5dp
A7	C1	R2	20d	50%	10dp
A8	C1	R2	10d	100%	10dp

For the production project in Fig. 1, the slack-based BACKWARD sequencing list of activities is presented in Table 2, and the related resources load reports and project schedule are depicted in Fig. 3.

Table 2

Slack-based BACKWARD sequencing list of activities

Job	Ranking rule	Resource	Processing time	Resource share	Load
A8	C1	R2	10d	100%	10dp
A7	C3	R2	20d	50%	10dp
A6	C3	R1	10d	50%	5dp
A3	C3	R2	20d	100%	20dp
A5	C3	R1	15d	100%	15dp
A2	C3	R1	10d	50%	5dp
A4	C1	R2	5d	50%	2,5dp
A1	C1	R1	10d	100%	10dp

As appears in Table 2, the ranking rule for most of the project's activities is the slack time rule (*C3*). The following slack times (*m*) in days were used for creating the sequencing list of activities in Table 2:

m(A1) = 0;
m(A2) = 0;
m(A3) = 0;
m(A4) = 15;
m(A5) = 5;
m(A6) = 0;
m(A7) = 0;
m(A8) = 0.

This data came from a complete PERT-time calculation for the example project.

When comparing the schedules in Figs. 2 and 3, it can be noticed that the project's flow time is 5 days shorter in the case of queue-based sequencing scenario. Actually, the authors' experience in managing production projects shows that the queue-based sequencing scenarios are usually more favorable than slack-based sequencing scenarios when the flow time of the projects is the only performance criterion. A possible cause of this situation may be the supplementary sequencing rule that is used in the latter scenarios.

3. CONCLUSIONS

In the first place, this paper shows the great interest of the management-area researchers in the project-scheduling optimization. Consequently, a huge work has been done in this field, from mid-1950s until now.

As the main goal of scheduling is to manage optimally the queues at bottleneck work centers, some well-known sequencing rules dedicated to this purpose are presented in the beginning of the paper. Some shortcomings of these rules are presented also.

Taking into account the limitations of the existing rule-based project scheduling models, a new view on sequencing problem is advocated in the remainder of the paper. This approach is mostly based on the authors' long experience in directing production projects, by contract or academically.

Two types of sequencing scenarios based upon some quantifiable sets of priority rules for activities are debated. These scenarios were tested on a simple production project to verify their qualities and limits. The proposed scenarios can be easily implemented into software applications for computer-aided project scheduling.

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Authors:

Dr. Eng., Corneliu NEAGU, Professor, "Politehnica" University of Bucharest, Production Engineering (TCM) Department, E-mail: necor_upb@yahoo.com

Dr. Eng., Mădălin-Gabriel CATANĂ, Lecturer, "Politehnica" University of Bucharest, Production Engineering (TCM) Department, E-mail: mg_catana@yahoo.com

Ph.D. Student Eng., Maria-Magdalena ROŞU, Assist. Prof., "Politehnica" University of Bucharest, Production Engineering (TCM) Department, E-mail: magdalenarosu@yahoo.com

Dr. Eng., Lucia-Violeta MELNIC, Lecturer, "Ovidius" University of Constanța, Faculty of Mechanical Engineering, E-mail: lmelnic@univ-ovidius.ro