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Article

Critical path method utilization for optimal scheduling of production activities

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ABSTRACT

Critical Path Method (CPM) is a useful method for scheduling activities involved in a project. CPM is suitable for large and complex projects in which many tasks are involved and the interrelationships among these tasks must be taken into account. Its efficacy can easily be transferred to the optimal scheduling of production engineering activities in order to save time involved in the project. It helps in identifying the sequence of jobs that determines the earliest possible completion date for the project. The knowledge of the critical jobs can aid in eliminating the fairly common and costly practice of rushing all jobs to reduce the total project time. Meanwhile, rushing only the critical jobs will have the desired effect of decreasing the total project time. In this study, the critical path method was utilized in scheduling activities involved in the production of a new product by a metalworks manufacturing company. The project activities involved making an initial market study which took 25 days, developing promotional ideas which took 22 days, estimating promotional costs which took 16 days, conducting initial pricing study which took 29 days, preparing a detailed design which took 30 days, manufacturing prototypes which took 14 days, making design changes which took 12 days and determination of the final selling price of the product which took 15 days. The critical path analysis revealed that the minimum allowable time and earliest possible completion date for the project is 96 days. This research provides a procedure for implementing the Critical Path Method for production activities scheduling.

1. Introduction

Production activities scheduling is very important for planning the sequence of tasks, allocating resources, and defining timelines to ensure that a production project is completed efficiently and on time. The key steps in scheduling include defining the project scope and objectives, identifying tasks and activities, determine task dependencies, estimating durations, allocating resources, developing the production schedule, optimizing the schedule and monitoring and controlling the operations. Defining the project scope and objectives involves identifying deliverables by clearly defining what the project aims to achieve and the specific deliverables expected at the end [1]. It also involves establishing clear, measurable objectives that align with the project goals. Identifying tasks and activities includes breaking down work into smaller, manageable tasks or activities. It also involves defining the tasks in detail, including what needs to be done, who will do it, and any necessary resources. Determining task dependencies involves identifying which tasks must be completed before others can begin. Estimating durations involves estimating how long each task will take to complete, using historical data, expert judgement or statistical methods, including making provisions for time buffers that have high uncertainty or risk [2]. Allocating resources involves assigning necessary resources such as people, equipment and materials to each task as well as identifying and addressing any resource constraints or limitations. Developing the schedule involves using scheduling tools like Gantt charts to create a visual timeline of the project as well as identifying key milestones that signify important progress points in the project [3]. Optimizing the schedule involves identifying the longest path through the network diagram that determines the shortest possible project duration as well as making adjustments to balance the schedule, considering resource availability, task dependencies and deadlines [4]. Monitoring and controlling involves tracking progress of tasks against the schedule, updating the schedule and communicating to stakeholders about the schedule status and any changes in the schedule. The Critical Path Method (CPM) is a project management technique for identifying the critical path, which is the sequence of tasks that determines the minimum project duration. It is used in determining the sequence of activities that directly affects the project completion time. By identifying the critical path, project managers can focus on tasks that cannot be delayed without impacting the overall project schedule. The method has been utilized in several applications including manufacturing, construction, agriculture, healthcare etc [5-8]. CPM has numerous advantages including enhanced project planning, identification of critical activities that directly impact the project timeline, improved resource allocation to critical tasks, risk management since bottlenecks and delays are identified as well as provision of clear timelines for project completion, aiding in settling realistic deadlines. The limitations of CPM include complexity for large projects with many tasks and dependencies, rigidity and less flexibility for projects with high uncertainty or where tasks are not clearly defined, as well as the fact that resource limitations are not considered which might affect the schedule. The aim of this work is to utilize the CPM for scheduling activities in a product development project involving the manufacture of a new filing cabinet design considering design, promotion and selling price. The study provides a procedure for implementing the CPM project scheduling method for scheduling production activities in a product development project.

2. Methodology

This study utilizes the CPM for scheduling activities in a product development project. CPM is suitable for large and complex projects in which many tasks are involved and the interrelationships among these tasks must be taken into account. The method is useful for determining the minimum time in which a production project can be completed and to ascertain the tasks that are likely to delay this completion, by identifying the most time-consuming series of tasks, which represent the critical path [9]. The knowledge of the critical jobs can aid in eliminating the fairly common and costly practice of rushing all jobs to reduce the total project time. Meanwhile, rushing only the critical jobs will have the desired effect of decreasing the total project time. The product development project involves the manufacture of a new filing cabinet design considering design, promotion and selling price. The project has been described in Table 1.

Table 1 shows the jobs that must be performed, the immediate predecessor(s) for each job and the estimated time requirements. From Table 1, jobs with not real predecessors are preceded by “Start” and jobs with no real successors are followed by “Finish”. Both types of jobs do not require any time. After this phase of the CPM analysis, it is necessary to prepare a project graph. The project graph is useful for understanding the computations involved in the CPM analysis. The project graph is a pictorial representation of the jobs that make up a project and their interrelationships. In constructing the project graph, a rectangle is used to depict each job, and the rectangle will contain the letter or number identification of the job and the time estimated for its completion. From any one rectangle, arrows are drawn to all the immediate successor jobs. Using the project graph, the minimum time required to complete the project can be ascertained. This is usually done by enumerating the different routes or paths that can be followed from the start to the finish of the project. The minimum amount of time required to complete the project will be determined by the most time-consuming sequence of jobs, which constitute the critical path. A project graph showing the early start and finish times needs to be developed as well as a project graph showing the late start and finish times. In developing the early start and finish times project graph S is the earliest possible starting time for the project, ES is the earliest possible starting time for a given job, t is the time required to complete a given job, EF = ES + t is the earliest possible finish time for a given job, F is the earliest possible finish time for the project. In developing the late start and finish times project graph, T is the target completion time for the project or the latest possible finish time for the project, LF is the latest possible finish time for a given job if the target completion time T is to be met, t is the time required to complete a given job and LS = LF – t is the latest possible starting time for a given job if the target completion time T is to be met.

Table 1. Product development project description

Job	Description	Immediate Predecessors	Required Time (Days)
A	Start	-	0
B	Conduct initial market study	A	25
C	Develop promotional ideas	B	22
D	Estimate promotional costs	C	16
E	Make initial pricing study	B	29
F	Develop a detailed product design	B	30
G	Manufacture prototypes	F	14
H	Make necessary design changes	G	12
I	Determine final selling price	D, E, H	15
J	Finish	I	0

3. Results and discussion

The results of applying the CPM methodology described in section two (2) is presented in this section. Two separate project graphs were developed for analyzing the project scheduling problem; the early start and finish times project graph as well as the late start and finish times project graph. The early start and finish times project graph is shown in Figure 1.

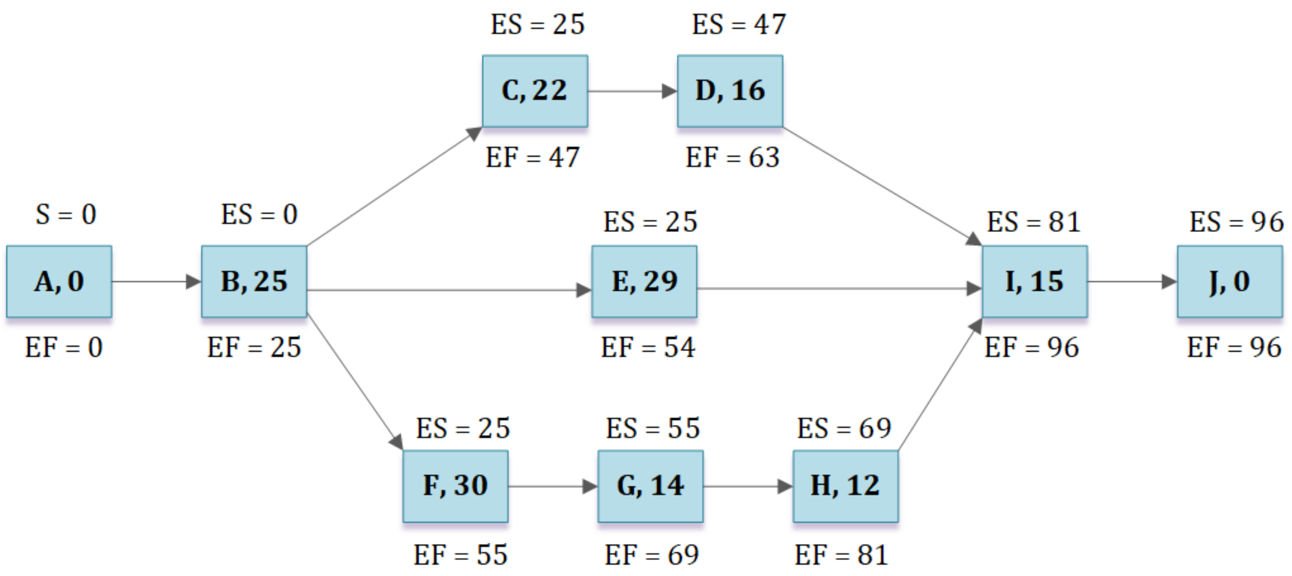

Figure 1. Early start and finish times project graph

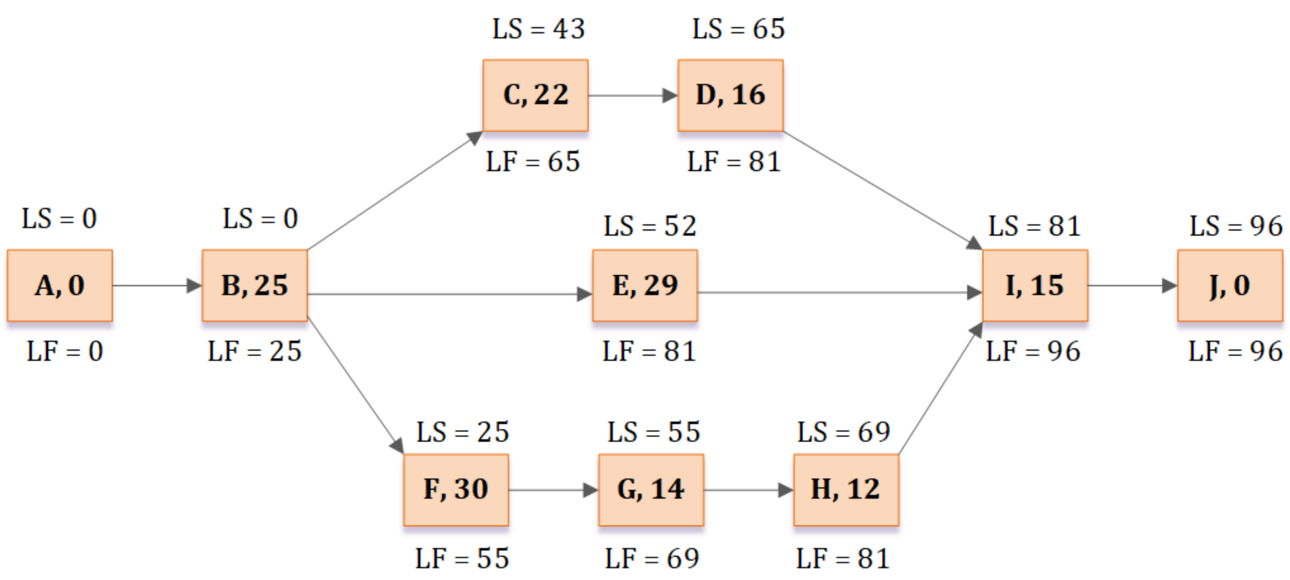

Figure 2. Late start and finish times project graph

Figure 1 shows the earliest points in time at which each job can be started and finished. From Figure 1, beginning with the first job A, the earliest possible starting time for the project S is 0 days. Because the time t for job A is 0 days, its early finish time EF will be the starting time of 0 days plus the required completion time of 0 days, which yields 0 days. Next is job B which can be started no sooner than when its immediate predecessor A is finished, therefore its early start time ES will be equal to its immediate predecessor's early finish time which was found to be 0. To obtain the early finish time for job B, its early start time of 0 days is taken and added to the 25 days required to perform the job, thereby arriving at an early finish time of 25 days. The early finish time of 25 days for job B is the early start time for its immediate successors C, E, and F.

The early finish time of job C is 47 days, the early start time for job D is the early finish time of its immediate predecessor job C, which is 47 days and the early finish time for job D is 63 days. The early finish time of job E is the early finish time of its predecessor plus the time taken to complete the job giving 54 days. The early finish time of job F is 55 days which is the early finish time of its predecessor plus the 30 days taken to complete the job. From the foregoing, the early finish time of job G is 69 days and the early finish time of job H is 81 days.

On getting to job I, it can be seen that the job has three immediate successor jobs, D, E and H. Moreover, jobs D, E and H have early finish times of 63 days, 54 days and 81 days. However, job I cannot be started until all three of its predecessor jobs are finished. Therefore, the early start time of job I is governed by the early finish time of job H, because it is the latest early finish time among the predecessor jobs. Therefore, the early start time of job I is 81 days. The early finish time of job I is the early start time plus the 15 days required to complete the job, giving 96 days, which is the early start time of job J. Finally, the early finish time of job J is the early start time of 96 days plus the 0 days required to complete the job which gives 96 days. The late start and finish times project graph is shown in Figure 2.

Figure 2 shows the latest points in time at which each job must be started and finished if the target completion date is to be met. The procedure utilized in obtaining the desired late times is the opposite of the one followed to obtain the early start and finish times. Therefore, we begin with the target completion time for the last job and work backward until we reach the late start time for the first job. The target completion time for the project is taken to be T = 96 days. Given this late finish time of 96 days and a required time of 0 days to complete job J, the late start time for this job is the difference between those two times, giving 96 days. Considering the preceding job I, the late finish time must be equal to the late start time of J. Therefore, the late finish time is 96 days, and the late start time is 96 days minus the time required for job I. This process continues until job B where there are three (3) successors to the job namely C, E and F. These successors have late start times of 43 days, 52 days and 25 days, respectively, therefore the late finish time of job B will be governed by the late start time of job F. This is because it is the earliest and more demanding late start time. Consequently, the late start times for jobs A and B become 0. Table 2 shows the determination of slack times for the production project. From Table 2, the slack time column contains the slack time in days for each job. This time is the difference between the late start time and the early start times for a job or between the late finish time and the early finish times for the job. The slack times represent the total allowable delay in the completion of all the jobs. Therefore, the minimum allowable time for the project is 96 days.

Table 2. Determination of slack times

Job	Possible start times		Possible finish times		Slack time (LS – ES) or (LF – EF)
	Earliest (ES)	Latest (LS)	Earliest (EF)	Latest (LF)	
A	0	0	0	0	0
B	0	0	25	25	0
C	25	43	47	65	18
D	47	65	63	81	18
E	25	52	54	81	27
F	25	25	55	55	0
G	55	55	69	69	0
H	69	69	81	81	0
I	81	81	96	96	0
J	96	96	96	96	0

4. Conclusion

The Critical Path Method comprises of construction of project graphs, determination of critical path and calculation of job slack times. The method is useful for determining the probable completion dates of production projects, as well as developing alternative plans. It helps in identifying the sequence of jobs, which are the critical jobs, that determines the earliest possible completion date for the project. The knowledge of the critical jobs can aid in eliminating the fairly common and costly practice of rushing all jobs to reduce the total project time. Meanwhile, rushing only the critical jobs will have the desired effect of decreasing the total project time. The knowledge of slack times associated with each job in the project is useful for developing work schedules. This study has utilized the critical path method for scheduling activities involved in the production of a new product by a metalworks manufacturing company. The project activities involved making an initial market study, developing promotional ideas, estimating promotional costs, conducting initial pricing study, preparing a detailed design, manufacturing prototypes, making design changes and determination of the final selling price of the product. The critical path analysis revealed that the minimum allowable time for the project is 96 days. This research provides a procedure for implementing the Critical Path Method for production activities scheduling. Further research can involve the utilization of other production scheduling methods such as the Program Evaluation and Review Technique (PERT) for effective production activities scheduling.

Ethical issue

The author is aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The author adheres to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

The manuscript contains all the data. However, more data will be available upon request from the author.

Conflict of interest

The author declares no potential conflict of interest.

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