UTILIZING MICROSOFT EXCEL FOR CRITICAL PATH METHOD (CPM) PROBLEM SOLVING: A PRACTICAL DEMONSTRATION FOR ENGINEERING STUDENTS

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ABSTRACT :
This short communication presents a practical demonstration of utilizing Microsoft Excel for solving Critical Path Method (CPM) problems. The CPM is a method used to determine the order of longest dependent tasks and find the least time required for its completion. By employing Excel's features and functions effectively, engineering students will learn how to determine the critical path and calculate project duration. Step-by-step instructions and screenshots are provided to guide the students through the process, making it accessible to both beginners and experienced Excel users alike. The algorithm and procedure are explained with the help of a typical CPM problem. Through this demonstration, the students will gain valuable insights into utilizing Excel as a powerful tool for Industrial engineering.
Keywords:CPM, critical path, project management, Microsoft Excel, spreadsheet

INTRODUCTION :
In project management, where timelines are constricted, uncertainties overflow, and resources are restricted, having a strong methodology to plan, monitor, and execute projects is essential. Herein lies the significance of the CPM i.e. the Critical Path Method, a foundational method that has revolutionized project management across diverse industries.CPM provides project managers with a systematic approach to analyse complex projects, break them down into manageable tasks, and determine the most efficient path to project completion. Originating from the fields of operations research and industrial engineering, CPM gained widespread adoption in the mid-20th century and has since become a cornerstone of modern project management practices[1].At its core, CPM revolves around the concept of sequencing activities and identifying dependencies to reveal the critical path i.e. the sequence of activities that determines the shortest possible duration for project completion. By concentrating on the critical activities, project supervisors can allocate resources sensibly, lessen potential delays, and ensure timely delivery of the project [2].The importance of CPM transcends its application as a mere scheduling tool; it serves as a strategic compass guiding project teams through the intricacies of project execution[3]. By harnessing CPM, project managers can anticipate bottlenecks, optimize resource utilization, and navigate the complexities inherent in large-scale projects.In essence, CPM epitomizes the synergy between theoretical rigor and practical application in project management. Its principles are grounded in mathematical models and algorithmic analyses, yet its impact reverberates in the real-world realm of project execution[4]. As organizations strive for greater efficiency, agility, and innovation, CPM remains an invaluable tool for achieving project success in an increasingly competitive landscape. Some important definitions and terminologies used in CPM analysis are:

- **Activity:**It is a task or set of tasks that must be completed to finish a project. Every activity has a specific duration and depends on other activities.
- **Predecessor:**It is an activity that must be completed before the start of another activity.
- **Successor:**Is an activity whose starting time depends on the completion of another activity.
- **Duration:**Refers to the completion time of an activity.
- **Early Start (ES)**: Is the earliest possible time an activity can start.
- **Early Finish (EF):** Is the earliest possible time an activity can be Finished.

- **Late Start (LS):**Is the latest possible time an activity can begin without delaying the overall time of the project.
- **Late Finish (LF):**Is the latest possible time an activity can be completed without delaying the overall time of the project.
- **Critical Path:**It is the longest path through the project network, comprising activities with zero slack value.

This article sheds light on the role that Microsoft Excel in the field of Mechanical Engineering, particularly in project management skills, likeCPM analysis. For students, mastering Excel goes beyond mere spreadsheet capability; it becomes a gateway to unlocking the competence for efficient project planning and scheduling[5–7]. Through the step-by-step demo provided in the article, students can grasp not only the theoretical concepts of CPM but also the practical execution using a familiar and widely amicable tool like Excel.By leveraging Excel's functionalities, such as formulas and conditional formatting tools, students can effectively tackle complex project schedules, identify critical paths, and optimize resource allocation[8,9]. This practical skill set not only enhances academic learning but also prepares students for real-world engineering challenges where project management is intrinsic.Additionally, the ability to utilize Excel for CPM analysis equips students of core engineering with a competitive edge in the job market.

CPM ALGORITHM :

The followingalgorithmic approach to project scheduling offers a complete understanding of activity timing, dependencies, and criticality, enabling effective resource allocation and ultimately project management.

a) Determination of ES and EF:
- ES and EF are calculated for each activity to establish the earliest possible start and finish times.
- Activities without predecessors commence at ES=0.
- EF is derived by adding activity duration to ES.
- For activities with a single predecessor, ES equals the EF of the predecessor.
- Activities with multiple predecessors set ES as the maximum EF among predecessors.

b) Predecessor to Successor Transformation:
- Predecessor Activities (PA) are inverted to identify Successor Activities (SA).
- This step establishes the sequential flow of activities within the project.

c) LF and LS Calculation:
- LF and LS are determined for each activity to ascertain the latest probable start and finish times without deferring the project timeline.
- Activities without successors (SA) conclude at the Time of Completion (TOC).
- LS is computed by subtracting duration from LF.
- For activities with a single successor, LF equals the LS of the successor.
- Activities with multiple successors synchronize with the earliest among them, setting LF as the minimum LS.

d) Slack Computation:
- Slack measures the flexibility or float time available for each activity.
- It is calculated as the difference between the LF and EF, or LS and ES.
- Activities with zero slack are termed critical, indicating they directly impact project duration.

e) Identification of Critical Activities and Path:

- Critical activities are those with zero slack, signifying any delay would outspread the project duration.
- The Critical Path encompasses a critical activities sequence that jointly determine the shortest project duration.

EXCEL METHODOLOGY :

The methodology mentioned in the previous section will be demonstrated in the Excel with the help of one typical CPM problems.

Problem: Find the critical path of the following problem:

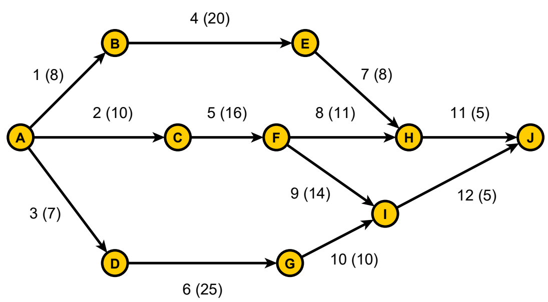

Fig. 1: Typical project management problem

In the problem the activities are numbered from 1 to 11 and the activity duration is written in the parentheses beside the activity number. The first thing is two make a templet to perform the computations as shown in Fig. 2.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	CPM													
2	Connecting nodes	A-B	A-C	A-D	B-E	C-F	D-G	E-H	F-H	F-I	G-I	H-J	I-J	TOC
3	Activity	1	2	3	4	5	6	7	8	9	10	11	12	
4	Predecessor Activity (PA)													
5	Duration (T=Time)													
6	Early Start (ES)													
7	Early Finish (EF)													
8	Successor Activity (SA)													
9	Late Start (LS)													
10	Late Finish (LF)													
11	Slack													
12	Critical Activities													

Fig. 2: Setting up of Excel sheet for CPM calculations

Then writing the predecessor for all the activities along with the activity time. If there is no predecessor for any activity, then that cell is highlighted with yellow colour as shown in Fig. 3.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	CPM													
2	Connecting nodes	A-B	A-C	A-D	B-E	C-F	D-G	E-H	F-H	F-I	G-I	H-J	I-J	TOC
3	Activity	1	2	3	4	5	6	7	8	9	10	11	12	
4	Predecessor Activity (PA)				1	2	3	4	5	5	6	7,8	9,10	
5	Duration (T=Time)	8	10	7	20	16	25	8	11	14	10	6	5	

Fig. 3: supplying data for predecessor and Duration

Once this is done then the ES and EF of activities are evaluated based on point (a) of the algorithm. Now as the activities 1, 2, and 3 do not have predecessor so they will have zero ES. Therefore, cells

B6 to D6 will be supplied zero value. Then, in the EF section, at cell B7, the sum of ES and Time duration of activity 1 will be suppled (=B6+B5). Now this formula will be dragged for each activity. Fig. 4 (a) shows the formula whereas, Fig. 4(b) represents the respective numerical values.

CPM

Connecting nodes	A-B	A-C	A-D	B-E	C-F	D-G	E-H	F-H	F-I	G-I	H-J	I-J	TOC
Activity	1	2	3	4	5	6	7	8	9	10	11	12	
Predecessor Activity (PA)				1	2	3	4	5	5	6	7,8	9,10	
Duration (T=Time)	8	10	7	20	16	25	8	11	14	10	6	5	
Early Start (ES)	0	0	0										
Early Finish (EF)	=B6+B5	=C6+C5	=D6+D5	=E6+E5	=F6+F5	=G6+G5	=H6+H5	=I6+I5	=J6+J5	=K6+K5	=L6+L5	=M6+M5	

(a) Formula

CPM

Connecting nodes	A-B	A-C	A-D	B-E	C-F	D-G	E-H	F-H	F-I	G-I	H-J	I-J	TOC
Activity	1	2	3	4	5	6	7	8	9	10	11	12	
Predecessor Activity (PA)				1	2	3	4	5	5	6	7,8	9,10	
Duration (T=Time)	8	10	7	20	16	25	8	11	14	10	6	5	
Early Start (ES)	0	0	0										
Early Finish (EF)	8	10	7	20	16	25	8	11	14	10	6	5	

(b) Numerical Value

Fig. 4: setting up initial values of ES and EF

Though the EF is not the true value at the start as for most of the activities ES is not yet know. Now the ES for other activities has to be evaluated which will automatically update the EF. Activities 4 to 10 have single predecessor so the ES will the EF of respective predecessor whereas for the activities 11 and 12 the ES will be the maximum value of EF for their predecessors, as shown in Fig. 5. Also, the TOC is evaluated as the maximum of EF of all the activities and kept at cell N7 (=MAX(B7:M7)).

CPM

Connecting nodes	A-B	A-C	A-D	B-E	C-F	D-G	E-H	F-H	F-I	G-I	H-J	I-J	TOC
Activity	1	2	3	4	5	6	7	8	9	10	11	12	
Predecessor Activity (PA)				1	2	3	4	5	5	6	7,8	9,10	
Duration (T=Time)	8	10	7	20	16	25	8	11	14	10	6	5	
Early Start (ES)	0	0	0	=B7	=C7	=D7	=E7	=F7	=F7	=G7	=MAX(H7:I7)	=MAX(J7:K7)	
Early Finish (EF)	=B6+B5	=C6+C5	=D6+D5	=E6+E5	=F6+F5	=G6+G5	=H6+H5	=I6+I5	=J6+J5	=K6+K5	=L6+L5	=M6+M5	

(a) Formula

CPM

Connecting nodes	A-B	A-C	A-D	B-E	C-F	D-G	E-H	F-H	F-I	G-I	H-J	I-J	TOC
Activity	1	2	3	4	5	6	7	8	9	10	11	12	
Predecessor Activity (PA)				1	2	3	4	5	5	6	7,8	9,10	
Duration (T=Time)	8	10	7	20	16	25	8	11	14	10	6	5	
Early Start (ES)	0	0	0	8	10	7	28	26	26	32	37	42	
Early Finish (EF)	8	10	7	28	26	32	36	37	40	42	43	47	47

(b) Numerical Value

Fig. 5: Evaluation of ES (and automatically EF) for activities with predecessors

Now the successor activity for all the activities is obtained with the help of row 3 and 4, and the final completed row is shown in Fig. 6. The cells which do have any successor activity are highlighted with the green colour.

CPM

Connecting nodes	A-B	A-C	A-D	B-E	C-F	D-G	E-H	F-H	F-I	G-I	H-J	I-J	TOC
Activity	1	2	3	4	5	6	7	8	9	10	11	12	
Predecessor Activity (PA)				1	2	3	4	5	5	6	7,8	9,10	
Duration (T=Time)	8	10	7	20	16	25	8	11	14	10	6	5	
Early Start (ES)	0	0	0	8	10	7	28	26	26	32	37	42	
Early Finish (EF)	8	10	7	28	26	32	36	37	40	42	43	47	47
Successor Activity (SA)	4	5	6	7	8,9	10	11	11	12	12			

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Fig. 6: Evaluation of successor activity for each predecessor activity

Now LS an LF for each activity is evaluated based on the point (c) of algorithm. As activities 11 and 12 do not have any successor so their LF will be set to the TOC. For all the activities, the LS is set as the difference between LF and T as shown in Fig. 7. At this point one can notice that LS of activities except 11 and 12 comes out as negative. This is ok as the LF for all the remaining actives are not known yet and which are going to be evaluated next.

CPM

Connecting nodes	A-B	A-C	A-D	B-E	C-F	D-G	E-H	F-H	F-I	G-I	H-J	I-J	TOC
Activity	1	2	3	4	5	6	7	8	9	10	11	12	
Predecessor Activity (PA)				1	2	3	4	5	5	6	7,8	9,10	
Duration (T=Time)	8	10	7	20	16	25	8	11	14	10	6	5	
Early Start (ES)	0	0	0	=B7	=C7	=D7	=E7	=F7	=F7	=G7	=MAX(H7:I7)	=MAX(J7:K7)	
Early Finish (EF)	=B6+B5	=C6+C5	=D6+D5	=E6+E5	=F6+F5	=G6+G5	=H6+H5	=I6+I5	=J6+J5	=K6+K5	=L6+L5	=M6+M5	=MAX(B7:M7)
Successor Activity (SA)	4	5	6	7	8,9	10	11	11	12	12			
Late Start (LS)	=B10-B5	=C10-C5	=D10-D5	=E10-E5	=F10-F5	=G10-G5	=H10-H5	=I10-I5	=J10-J5	=K10-K5	=L10-L5	=M10-M5	
Late Finish (LF)											=N7	=N7	

(a) Formula

CPM

Connecting nodes	A-B	A-C	A-D	B-E	C-F	D-G	E-H	F-H	F-I	G-I	H-J	I-J	TOC
Activity	1	2	3	4	5	6	7	8	9	10	11	12	
Predecessor Activity (PA)				1	2	3	4	5	5	6	7,8	9,10	
Duration (T=Time)	8	10	7	20	16	25	8	11	14	10	6	5	
Early Start (ES)	0	0	0	8	10	7	28	26	26	32	37	42	
Early Finish (EF)	8	10	7	28	26	32	36	37	40	42	43	47	47
Successor Activity (SA)	4	5	6	7	8,9	10	11	11	12	12			
Late Start (LS)	-8	-10	-7	-20	-16	-25	-8	-11	-14	-10	41	42	
Late Finish (LF)											47	47	

(b) Numerical value

Fig. 7: Primary step of LS and LF evaluation

We will be moving from 10th activity till the first activity i.e. backwards. For the activities with single successor i.e. 1 to 4 and 6 to 10 the LF will be equal to the LS of the successor activity and for activity 5 the LF will be the minimum of the LS of its successors (as it has more than one successor). Once this is done the LS will automatically get updated as shown in Fig. 8.

CPM

Connecting nodes	A-B	A-C	A-D	B-E	C-F	D-G	E-H	F-H	F-I	G-I	H-J	I-J	TOC
Activity	1	2	3	4	5	6	7	8	9	10	11	12	
Predecessor Activity (PA)				1	2	3	4	5	5	6	7,8	9,10	
Duration (T=Time)	8	10	7	20	16	25	8	11	14	10	6	5	
Early Start (ES)	0	0	0	=B7	=C7	=D7	=E7	=F7	=F7	=G7	=MAX(H7:I7)	=MAX(J7:K7)	
Early Finish (EF)	=B6+B5	=C6+C5	=D6+D5	=E6+E5	=F6+F5	=G6+G5	=H6+H5	=I6+I5	=J6+J5	=K6+K5	=L6+L5	=M6+M5	=MAX(B7:
Successor Activity (SA)	4	5	6	7	8,9	10	11	11	12	12			
Late Start (LS)	=B10-B5	=C10-C5	=D10-D5	=E10-E5	=F10-F5	=G10-G5	=H10-H5	=I10-I5	=J10-J5	=K10-K5	=L10-L5	=M10-M5	
Late Finish (LF)	=E9	=F9	=G9	=H9	=MIN(I9:J9)	=K9	=L9	=L9	=M9	=M9	=N7	=N7	

CPM

Connecting nodes	A-B	A-C	A-D	B-E	C-F	D-G	E-H	F-H	F-I	G-I	H-J	I-J	TOC
Activity	1	2	3	4	5	6	7	8	9	10	11	12	
Predecessor Activity (PA)				1	2	3	4	5	5	6	7,8	9,10	
Duration (T=Time)	8	10	7	20	16	25	8	11	14	10	6	5	
Early Start (ES)	0	0	0	8	10	7	28	26	26	32	37	42	
Early Finish (EF)	8	10	7	28	26	32	36	37	40	42	43	47	47
Successor Activity (SA)	4	5	6	7	8,9	10	11	11	12	12			
Late Start (LS)	5	2	0	13	12	7	33	30	28	32	41	42	
Late Finish (LF)	13	12	7	33	28	32	41	41	42	42	47	47	

Fig. 8: Final updated values of LS and LF

Now the slack is evaluated either by subtracting LF and EF or LS and ES. Solving it for cell B11 and then dragging for other activity cells, the result is shown in Fig. 9.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1						CPM								
2	Connecting nodes	A-B	A-C	A-D	B-E	C-F	D-G	E-H	F-H	F-I	G-I	H-J	I-J	TOC
3	Activity	1	2	3	4	5	6	7	8	9	10	11	12	
4	Predecessor Activity (PA)				1	2	3	4	5	5	6	7,8	9,10	
5	Duration (T=Time)	8	10	7	20	16	25	8	11	14	10	6	5	
6	Early Start (ES)	0	0	0	8	10	7	28	26	26	32	37	42	
7	Early Finish (EF)	8	10	7	28	26	32	36	37	40	42	43	47	47
8	Successor Activity (SA)	4	5	6	7	8,9	10	11	11	12	12			
9	Late Start (LS)	5	2	0	13	12	7	33	30	28	32	41	42	
10	Late Finish (LF)	13	12	7	33	28	32	41	41	42	42	47	47	
11	Slack	5	2	0	5	2	0	5	4	2	0	4	0	

Fig. 9: Slack evaluation

To evaluate the critical path, one has to mark the critical activities i.e. the one for whom the slack is zero. So the last step of calculation is set the if condition in the cell B12 to check whether the activity is critical or not by using the formula: =IF(B11=0,"CA"," "). It says that if the cell B11 has slack 0 then mark it as CS else leave it as it. Then drag this cell to fill for the remaining activities. The final Excell sheet with the critical activities are shown in Fig. 10.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1						CPM								
2	Connecting nodes	A-B	A-C	A-D	B-E	C-F	D-G	E-H	F-H	F-I	G-I	H-J	I-J	TOC
3	Activity	1	2	3	4	5	6	7	8	9	10	11	12	
4	Predecessor Activity (PA)				1	2	3	4	5	5	6	7,8	9,10	
5	Duration (T=Time)	8	10	7	20	16	25	8	11	14	10	6	5	
6	Early Start (ES)	0	0	0	8	10	7	28	26	26	32	37	42	
7	Early Finish (EF)	8	10	7	28	26	32	36	37	40	42	43	47	47
8	Successor Activity (SA)	4	5	6	7	8,9	10	11	11	12	12			
9	Late Start (LS)	5	2	0	13	12	7	33	30	28	32	41	42	
10	Late Finish (LF)	13	12	7	33	28	32	41	41	42	42	47	47	
11	Slack	5	2	0	5	2	0	5	4	2	0	4	0	
12	Critical Activities			CA			CA				CA		CA	

Fig. 9: Critical activities

One can observe that activities 3, 6, 10, and 12 are critical activities so the path connecting them will be critical and requires more attention. Fig. 10 shows the final updated version of Fig. 1 with critical activities and path marked with red colour.

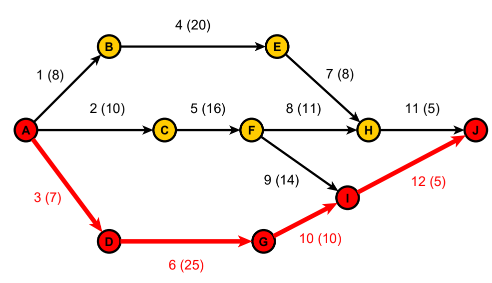

Fig. 10: Critical activities

CONCLUSION :

In this article CPM i.e. the critical path method has been discussed and implemented using Microsoft Excel. A detailed algorithm to solve any CPM problem has been presented which has been step by step solved so that the reader can independently follow the steps without any difficulty.In essence, this article emphasizes the importance for mechanical engineering students to embrace Excel as more than just a spreadsheet tool but rather as a powerful ally in their academic and professional journey.By mastering Excel for CPM analysis, students can enhance their problem-solving skills, improve project efficiency, and stand out in a competitive engineering landscape.

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