

Review on Using Packages to Enhance the Teaching of Critical Path Networks

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Abstract— The aim of this paper is to review a published paper, ‘Using computer software packages to enhance the teaching of Engineering Management Science: Part 1 –Critical path networks’. *Excel in Microsoft Office 2007* was discovered to be able to solve critical path network problems with some programming. The capabilities of the two previously evaluated packages, *Microsoft Project 2007* and *Quantitative Methods – Production and Operations Management (POM-QM) for Windows 3* were tested together with *Excel* against each of the objective of the module, critical path networks. A pseudo quantity scoring system was developed to evaluate the capabilities of the software packages in meeting the objectives of the module. It was found that *POM-QM* scored the highest points. However, *Excel* can be argued to provide the best learning outcomes as it endeavours students to understand the concepts of critical path networks clearly before they can program and solve the problems.

Index Terms— Critical path networks engineering management science, *Microsoft Project 2007*, and *Quantitative Methods – Production and Operations Management (POM-QM) for Windows 3*

I. INTRODUCTION

IN the paper, ‘Using computer software packages to enhance the teaching of Engineering Management Science: Part 1 –Critical path networks’, it was concluded that the application of software packages in *Engineering Management Science* is a ‘must’. For *critical path networks*, more than one package will be required; different packages will be required on different parts of the problem and no one package can satisfy the needs for beginners [1].

In the previous paper, it was found that both can be used to draw the CPA network diagrams but none of them is perfect as they can only draw them in activity-on-node. Only *POM-QM for Windows 3* can be used to evaluate the earliest start, earliest finish, latest start and latest finish times, and calculate the total float for all activities and present them in a table form; this still cannot satisfy all the requirements of objectives 3 and 4 of the modules as listed in Table 1 because the package cannot evaluate the free float and independent float [1]. For costing and crashing, *POM-QM for Windows 3* is more suitable for the course as the package can solve the costing and crashing at activity level. In

drawing Gantt chart and showing the critical path in the chart, *POM-QM for Windows 3* is more suitable as it is simpler to use. However, only *MS Project 2007* can perform resource leveling, which is a very important element in critical path networks in practice. On the other hand, only *POM-QM for Windows 3* can be used to evaluate the probabilistic networks. It appears that *POM-QM for Windows 3* is a better software for this module [1].

Table 1: Objectives of the module, critical path networks

Objectives	Details
1	recognize situations where the application of critical path analysis (CPA) is appropriate;
2	break down a project into a number of suitable activities and construct a CPA network showing how these activities are combined in a logical sequence representing the project from start to finish;
3	analyze activities in critical path network in terms of activity start and finish times;
4	calculate the float availability for all activities in a project network and use such float to maintain the critical project time;
5	construct a Gantt chart for a project and using the chart to undertake load smoothing and load reduction procedures;
6	use critical path analysis to determine the shortest possible and/or the most economical time based on direct and indirect cost analysis;
7	use critical path analysis to determine the completion time of probabilistic projects and the reliability of such projects being completed within the determined time.

In the last paper, a pseudo quantity evaluation method was employed, in which scores were allocated to each package when they satisfied a particular objective of the module. Score of 0 to 10 were awarded to each package for satisfying a particular objective, 10 being the highest and the package with highest total scores was considered to be more suitable software for the module. As the total scores for *POM-QM for Windows 3* (49) is higher than *MS Project 2007* (27), the former is therefore considered to be the more suitable package for the module [1].

In this paper, *Excel in MS Office 2007* will be tried in all objectives of the module, critical path networks. Each time, when *Excel* is tested for suitability of a particular objective of the module, the capabilities of the two previously used packages on the same objective will also be cited and discussed. Finally, a pseudo-quantitative score system will again be employed to evaluate the three packages to determine which one is the best for the module.

II. EXCEL IN OBJECTIVE 1

Neither *Excel*, nor the other two packages can be used to recognize situations where the application of critical path analysis (CPA) is appropriate. Students have to decide the above case by themselves without the help of any package.

III. EXCEL IN OBJECTIVE 2

Figure 1 shows the *POM-QM for Windows 3* inputs for a project (used in previous paper) with activities, their duration and precedence, for constructing a critical path network. *Excel* cannot construct a CPA network showing

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Budgeting								
	Activity time	Prec 1	Prec 2	Prec 3	Prec 4	Prec 5	Prec 6	Prec 7
1-2	16							
1-3	20							
1-11	30							
2-8	15	1-2						
3-7	15	1-3						
3-8	10	1-3						
7-8	3	3-7						
7-11	16	3-7						
8-11	12	7-8	3-8	2-8				

Figure 1: A project with activities, their duration and precedence

how these activities are combined in a logical sequence representing the project from start to finish. This has to be done manually from information provided in Figure 1 and this is depicted in Figure 2. On the other hand, *POM-QM for Windows 3* can generate a network diagram as depicted in Figure 3 from inputs shown in Figure 1; the critical path of the network will also be generated at the same time. With inputs as depicted in the left part of Figure 4, *MS Project* will generate a network diagram with critical path for the project.

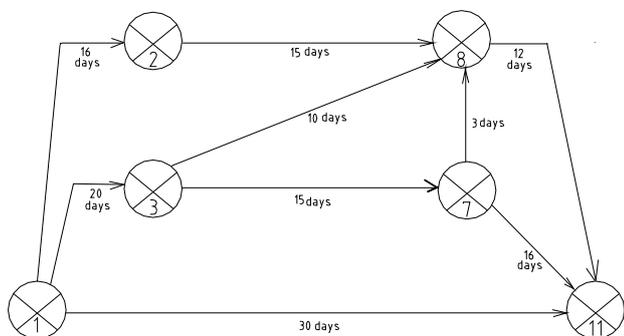


Figure 2: The network, its activities and durations

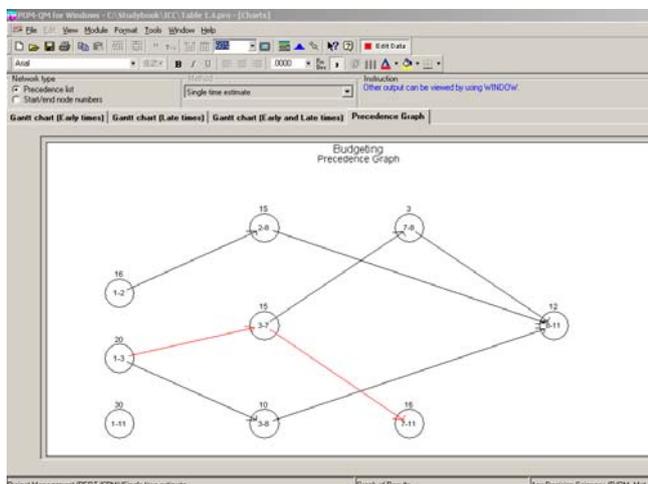


Figure 3: A network diagram with critical path shown using POM-QM for Windows 3

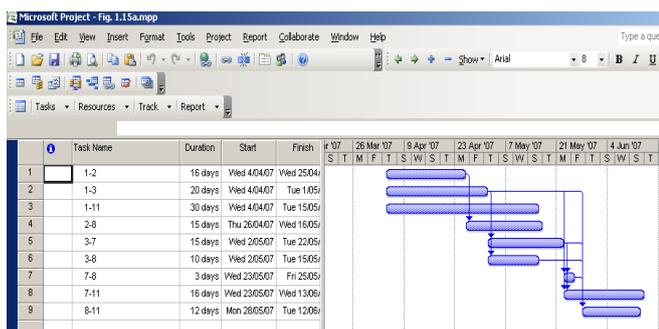


Figure 4: Input for network diagram and Gantt chart drawn by Microsoft Project standard 2007

IV. EXCEL IN OBJECTIVE 3

Excel can analyze activities in critical path networks in terms of activity start and finish times by inputting the information into the spreadsheet as depicted in Figure 5.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Activities	SD	D	Nodes	Start	Finish	CP=0	ES	LS	EF	LF	TF	FF	IF
2														
3	1-2	0	16	1	0	0	0							
4	1-3	0	20	2										
5	1-11	0	30	3										
6	2-8	16	15	7										
7	3-7	20	15	8										
8	3-8	20	10	11										
9	7-8	35	3											
10	7-11	35	16											
11	8-11	38	12											

Figure 5: Inputs to Excel for evaluating node start and finish times

Start time for 'node 2' is calculated by referring to the network diagram of the project and adding the duration of 'activity 1-2' to start time of 'node 1', i.e. $16 + 0 = 16$ or inputting $=E3+C3$ into cell E4 as depicted in Figure 5. Similarly, start time for 'node 3' is calculated by adding the duration of 'activity 1-3' to start time of 'node 1', i.e. $20 + 0 = 20$ or inputting $=E3+C4$ into cell E5. However, start time for 'node 7' is calculated by adding the duration of 'activity 3-7' to start time of 'node 3', i.e. $15 + 20 = 35$ or inputting $=E5+C7$ into cell E6. The start time of 'node 8' is more complicated to evaluate because three activities, '2-8', '3-7' and '7-8' terminate in 'node 8'. It has to be achieved by entering $=MAX(E4+C6,E5+C8,E6+C9)$ into cell E7. This is the equivalent of evaluating it manually using forward pass method. Similarly, start time of 'node 11' is evaluated by inputting $=MAX(E3+C5,E6+C10,E7+C11)$ into cell E8 [2]. All start and finish times for all nodes are shown in Figure 6; finish times will be worked out in the next paragraph.

	A	B	C	D	E	F	G
1	Activities	SD	D	Nodes	Start	Finish	CP=0
2							
3	1-2	0	16	1	0	0	0
4	1-3	0	20	2	16	24	1
5	1-11	0	30	3	20	20	0
6	2-8	16	15	7	35	35	0
7	3-7	20	15	8	38	39	1
8	3-8	20	10	11	51	51	0
9	7-8	35	3				
10	7-11	35	16				
11	8-11	38	12				

Figure 6: Nodes start and finish times and critical nodes (highlighted)

Finish time for 'node 11' is the start time of it, i.e. 51. This is the equivalent of evaluating it manually using backward pass method. Finish time for 'node 8', is calculated by taking the duration of 'activity 8-11' from finish time of 'node 11', i.e. $51 - 12 = 39$ or inputting $=F8-C11$ in cell F7. However, finish time of 'node 7' is more complicated because two activities, '7-11' and '7-8' come out from it. It has to be achieved by entering $=MIN(F8-C10,F7-C9)$ into cell F6. Similarly, finish time of 'node 3' is evaluated by inputting $=MIN(F6-C7,F7-C8)$ into cell F5. Finish time of 'node 2' is calculated by taking the duration of 'activity 2-8' from finish time of 'node 8', i.e. $39 - 15 = 24$ or inputting $=F7-C6$ into cell F4 [2].

Critical path is achieved by joining critical nodes, in which the difference between the start time and finish time of a node is zero. Critical nodes can be found by entering

'=IF(F3-E3=0,0,1)' in cell G2 and copy it through cells G3 through G8. Critical nodes are illustrated and highlighted in Figure 6 [2]. The critical path is therefore 1-3-7-11, i.e. lines joining the critical nodes are the critical path.

V. EXCEL IN OBJECTIVE 4

Excel can calculate the float availability for all activities in a project network and use such float to maintain the critical project time. To evaluate earliest start, latest start, earliest finish and latest finish of activities, it is necessary to refer to Figure 7. Earliest start of 'activity 1 - 2' is achieved by entering '=E3' i.e. start time of 'node 1' into cell H3; it is zero. Latest start of 'activity 1 -2' is achieved by inputting '=F4-C3', i.e. finish time of 'node 2' minus duration of 'activity 1 -2' into cell I3, i.e. 24 - 16 = 8. The evaluation has to refer to Figure 8. Earliest finish of 'activity 1 - 2' is calculated by entering '=H3+C3', i.e. adding earliest start of 'activity 1 -2' to its duration, 0 + 8 = 8 into cell J3. Latest finish of 'activity 1 - 2' is achieved by inputting '=F4', i.e. finish time of 'node 2' into cell K3; it is 24. The earliest start, latest start, earliest finish and latest finish of a particular activity can be achieved by manipulating the durations of the activity and the start and finish times of the relevant nodes as demonstrated in the previous sentences. In all cases, it is necessary to refer to Figure 7. The earliest start, latest start, earliest finish and latest finish of all activities are shown in Figure 8 [2].

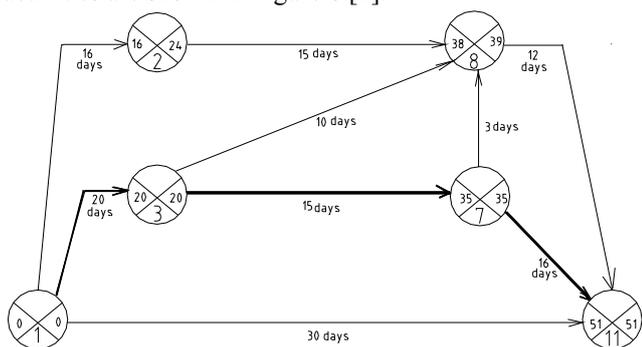


Figure 7: Network with critical path drawn

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Activities	SD	D	Nodes	Start	Finish	CP=0	ES	LS	EF	LF	TF	FF	IF
2														
3	1-2	0	16	1	0	0	0	0	8	16	24			
4	1-3	0	20	2	16	24	1	0	0	20	20			
5	1-11	0	30	3	20	20	0	0	21	30	51	21	21	21
6	2-8	16	15	7	35	35	0	16	24	31	39	8	7	0
7	3-7	20	15	8	38	39	1	20	20	35	35	0	0	0
8	3-8	20	10	11	51	51	0	20	29	30	39	9	8	8
9	7-8	35	3					35	36	38	39	1	0	0
10	7-11	35	16					35	35	51	51	0	0	0
11	8-11	38	12					38	39	50	51	1	1	0

Figure 8: Earliest start, latest start, earliest finish and latest finish of all activities

The final step is to evaluate the floats, starting with total float of 'activity 1 - 2'. This is achieved by entering '=F4-E3-C3', i.e. finish time of 'node 2' minus start time of 'node 1' minus the duration of 'activity 1 - 2' or 24 - 0 - 16 = 8 into cell L3. This has to be done by referring to Figure 7. Free float of 'activity 1 - 2' is achieved by inputting '=E4-E3-C3', i.e. start time of 'node 2' minus start time of 'node 1' minus the duration of 'activity 1 - 2' or 16 - 0 - 16 = 0 into cell M3. Similarly, this has to be done by referring to Figure 7. The independent float of the same activity is

achieved by inputting '=IF(E4-F3-C3<=0,0)', i.e. start time of 'node 2' minus finish time of 'node 1' minus the duration of the activity or 16 - 0 - 16 = 0 into cell N3. The 'IF' in cell N3 is to ensure that negative value becomes zero. This has also been done by referring to Figure 7. Similarly, the floats of a particular activity can be achieved by manipulating the durations of the activity and the start and finish times of the relevant nodes as demonstrated in the previous sentences. The total float, free float and independent float of all activities are shown in Figure 9.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Activities	SD	D	Nodes	Start	Finish	CP=0	ES	LS	EF	LF	TF	FF	IF
2														
3	1-2	0	16	1	0	0	0	0	8	16	24	8	0	0
4	1-3	0	20	2	16	24	1	0	0	20	20	0	0	0
5	1-11	0	30	3	20	20	0	0	21	30	51	21	21	21
6	2-8	16	15	7	35	35	0	16	24	31	39	8	7	0
7	3-7	20	15	8	38	39	1	20	20	35	35	0	0	0
8	3-8	20	10	11	51	51	0	20	29	30	39	9	8	8
9	7-8	35	3					35	36	38	39	1	0	0
10	7-11	35	16					35	35	51	51	0	0	0
11	8-11	38	12					38	39	50	51	1	1	0

Figure 9: Total float, free float and independent float of all activities

With the same input in Figure 1, POM-QM for Windows 3 can generate start and finish times of nodes, earliest start, latest start, earliest finish and latest finish of activities and total float, free float and independent float of all activities in one click and is illustrated in Figure 10 [1].

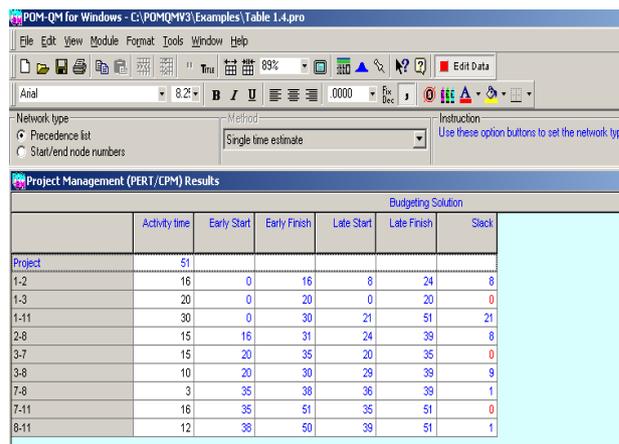


Figure 10: Start and finish times of nodes, earliest start, latest start, earliest finish and latest finish of activities and total float, free float and independent float of all activities

MS Project is also able to evaluate the earliest start, earliest finish, latest start and latest finish times, and total float (slack), free float of the activities of a network and list them in a table. However, the procedures required to do so are tedious and it is not suitable for beginners [1].

VI. EXCEL IN OBJECTIVE 5

Excel can construct a Gantt chart for a project and use the chart to undertake load smoothing and load reduction procedures. The inputs required are as shown in Figure 5 and this time the information in column 'B' will be used. It is the starting date of the activity and is on the left hand side of Figure 5. Highlight A3:C11, i.e. activities, start date of activities and duration of activities. Click Chart Wizard. Select Bar, Select Staked Bar (second on upper row). There is basically a Gantt chart in which horizontal bars have two colours and activities appear along the vertical axis. The first part of each bar represents the time from day 0 to the starting date of an activity, the second part, the start and end

times of each activity. Since, one is not interested in the number of days from day 0 until the start of an activity, one wants to make the first section of each bar invisible. This is achieved by double-clicking on the first part of any bar; this should bring up the Patterns dialog box for the first data series. In the Pattern portions, set the colour to white. Click **O.K.** To change the background to white, click the grey background. Click Format Plot Area. When the Patterns dialog box appears, set the colour to white. Click **O.K.** To reverse the vertical axis, select the vertical axis and choose the Scale command. In the dialog box, select the check box labeled Categories in Reverse Order, and then click **O.K.** The Gantt chart is complete and is depicted in Figure 11 [2].

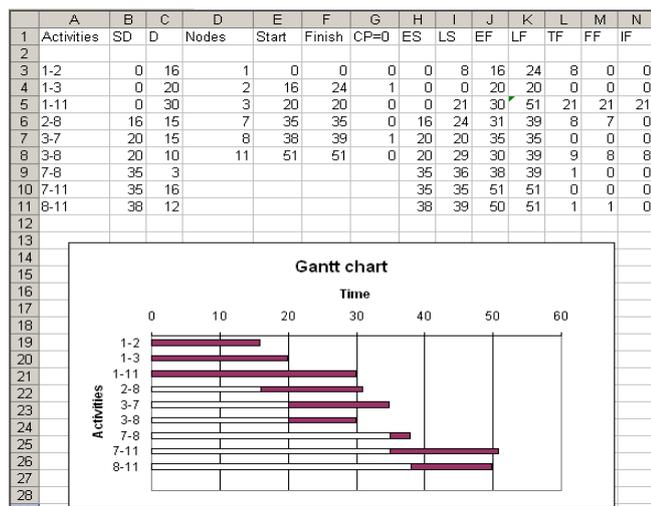


Figure 11: Completed Gantt chart

With the same input in Figure 1, *POM-QM for Windows 3* can generate overlapping Gantt charts with earliest start and finish as well as latest start and finish as depicted in Figure 12. The floats are on the overlapping parts. Users would be able to recognize the possible movement of the activities to level resources either manually or using software packages. With inputs as depicted in the left part of Figure 4, *MS Project* will generate a Gantt chart for the project is as illustrated in right hand side of Figure 4 [1].

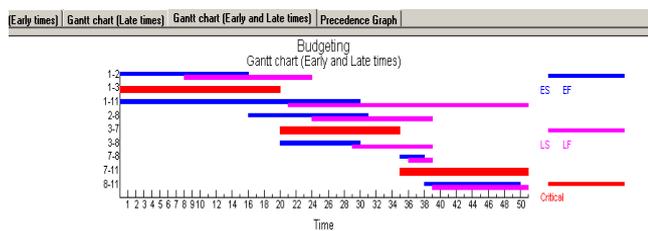


Figure 12: Overlapping Gantt charts using POM-QM for Windows 3

VII. EXCEL IN OBJECTIVE 6

Excel can use critical path analysis to determine the shortest possible and/or the most economical time based on direct and indirect cost analysis. To illustrate crashing a project using *Excel*, the same crashing data employed in the previous paper will be used [1]. The network of the data is the same one discussed in this paper.

Figure 13 shows the inputs required for crashing the network using *POM-QM for Windows 3*. The same inputs for *Excel* are depicted in Figure 14. At the top of the

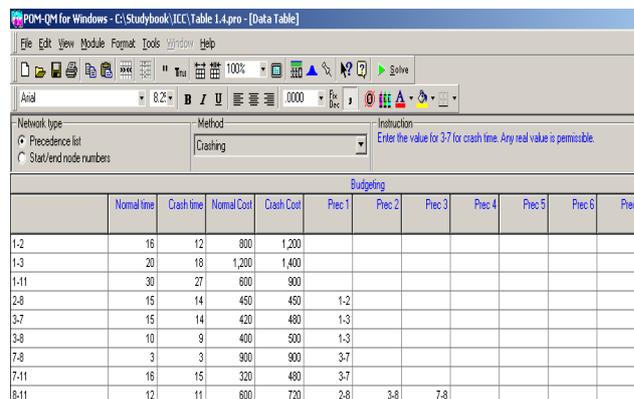


Figure 13: Inputs required for crashing using POM-QM for Windows 3

	A	B	C	D	E	F	G	H	I	J	K
1	Deadline	51									
2	Total cost	5690									
3											
4			Normal duration	Crash duration	Normal cost	Crash cost	Cost /day	Maxim. crash	Amt. to crash	Crashing cost	Actual time
5	Activity	Preced.									
6	1-2	-	16	12	800	1200	100	4	0	0	16
7	1-3	-	20	18	1200	1400	100	2	0	0	20
8	1-11	-	30	27	600	900	100	3	0	0	30
9	2-8	1-2	15	14	450	450	0	1	0	0	15
10	3-7	1-3	15	14	420	480	60	1	0	0	15
11	3-8	1-3	10	9	400	500	100	1	0	0	10
12	7-8	3-7	3	3	900	900	NA	0	0	0	3
13	7-11	3-7	16	15	320	480	160	1	0	0	16
14	8-11	2-8	12	11	600	720	120	1	0	0	12
15						5690					
16											
17											
18	Node	Event time									
19	2	0									
20	3	0									
21	7	0									
22	8	0									
23	11	0									
24											
25	Key Formulae										
26	B2	=E15+J15									
27	G6	=(F6-E6)/(C6-d6) {copy to G7:G14}									
28	H6	=C6-D6 {copy to H7:H14}									
29	J6	=I6*G6 {copy to J7:J14}									
30	K6	=C6-I6 {copy to K7:K14}									

Figure 14: Inputs required for crashing using Excel

spreadsheet the specified deadline is entered in cell B1 and the total cost of completing the project including both normal cost and crash cost is calculated in cell B2. Below this column, columns A to G contain the information for the calculation. Note that in column G, the crash cost per day is calculated by dividing the incremental cost of crashing the activity as much as possible by the maximum number of days the activity can be shortened [3].

In column H, the maximum amount each activity can be crashed is calculated by subtracting the crash duration from the normal duration. Column I corresponds to how much to crash each activity. Then based on the values input in column I, the cost of crashing each activity is calculated in column J. Finally, in column K, the actual time to complete the activity is calculated by subtracting the amount the activity is crashed (column I) from the activity's normal duration (column C) [3].

In cells A19:B23, another table was created to keep track of the event times of each node in the network diagram shown in Figure 2. Node 1 is excluded because it is assumed that this node occurs at time zero. This is to ensure that the precedence relationships in the network diagram are not violated. *Excel*'s Solver can be used to determine which activities to crash so that the entire project is completed within 47 days at the minimum costs. To begin, select **Tools** from the menu bar and then **Solver** from the next menu that appears. The Solver Parameter dialog box is now displayed in Figure 15 [3].

The Set Target **Cell** field refers to the cell in the spreadsheet that we would like to either minimize or maximize. In this case, it is to minimize the total cost of completing the project which is calculated in cell B2.

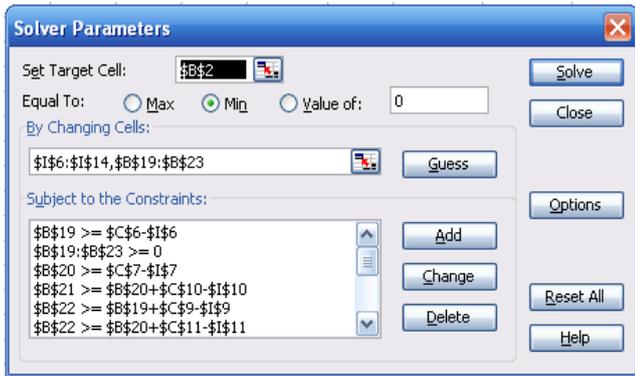


Figure 15: Excel's Solver loaded with date and constraints from crash problem

To specify this, B2 is entered in the **Set Target Cell** field and then select the **Min** ratio button [3].

The next step is to tell *Excel* what cells it can change in order to find the solution with the minimum total project completion cost. In Figure 14, the values or cells that can be changed are the amount of time each activity is crashed (cells I6:I14) and the time when each event occurs (cells B19:B23). Thus as is shown in Figure 15, these ranges were entered in the **By Changing Cells** field [3].

The final type of information required is the limitations or constraints associated with the situation. Perhaps, the most obvious constraint is that the project has to be completed in 47 days (cell B1). Since node 11 (cell B 23) corresponds to the event of the project being completed, it is necessary to specify this constraint as follows [3]:

$$B23 \leq B1$$

Another important set of constraints is needed to make sure an activity is not crashed more than the maximum number of days that it can be crashed. Constraints to ensure this could be entered as follows [3]:

$$I6:I14 \leq H6:H14$$

Another set of constraints is needed to ensure that the precedence relationships specified in the network diagram are not violated. This is done by keeping track of the event times of the nodes. For example, the event time of node 2 cannot occur until after activity 1-2 has been completed. The time to complete activity 1-2 is its normal time less the amount of time it is crashed. Since cell B19 corresponds to the event time of node 2, mathematically the constraint can be entered as follows [3]:

$$B19 \geq C6 - I6$$

Constraints for the other nodes could be created in a similar fashion. For examples the constraints for nodes 3 and 7 would respectively be

$$B20 \geq C7 - I7 \quad B21 \geq B20 + C10 - I10$$

Moving on to node 8, this node has three arrows pointing to it. A node with more than one arrow pointing to it will need a separate constraint for each arrow. Three constraints are required for node 8 [3]

$$B22 \geq B19 + C9 - I9 \quad B22 \geq B20 + C11 - I11 \quad B22 \geq B21 + C12 - I12$$

Node 11 is handled in a similar way to node 8 as follows [3]:

$$B23 \geq B21 + C13 - I13 \quad B23 \geq B22 + C14 - I14 \quad B23 \geq C8 - I8$$

Finally, since it does not make sense to crash an activity a negative amount of time, nor does it make sense for a node to occur at a time less than time zero, constraints are added

to ensure these outcomes are not generated. The constraints can be specified as follows [3]:

$$I6:I14 \geq 0 \quad B19:B23 \geq 0$$

After entering these constraints, the Solver Parameters dialog box appears as shown in Figure 15. Before finding the least costly way to crash the project down to 47 days, select the **Options ...** button and click on the **Assume Linear Model** check box and then click **OK**. Now to find the least cost solution, select the **Solve** button in the Solver Parameters dialog box. Figure 16 shows the solution, deadline 47 days (cell B1) and total cost 6100 (cell B2) [3].

1	Deadline	B1	47											
2	Total cost	B2	6100											
3														
4														
5	Activity	Preced.	Normal duration	Crash duration	Normal cost	Crash cost	Cost /day	Maxim. crash	Amt. to crash	Crashing cost	Actual time			
6	1-2	-	16	12	800	1200	100	4	0	0	16			
7	1-3	-	20	18	1200	1400	100	2	2	200	18			
8	1-11	-	30	27	600	900	100	3	0	0	30			
9	2-8	1-2	15	14	450	450	0	1	0	0	15			
10	3-7	1-3	15	14	420	480	60	1	1	60	14			
11	3-8	1-3	10	9	400	500	100	1	0	0	10			
12	7-8	3-7	3	3	900	900	NA	0	0	NA	3			
13	7-11	3-7	16	15	320	480	160	1	1	160	15			
14	8-11	2-8	12	11	600	720	120	1	0	0	12			
15					5690						420			
16														
17														
18	Node		Event time											
19		2	16											
20		3	18											
21		7	32											
22		8	35											
23		11	47											
24														
25	Key Formulae													
26	B2		=E15+J15											
27	G6		=(F6-E6)/(C6-d6) (copy to G7:G14)											
28	H6		=C6-D6 (copy to H7:H14)											
29	J6		=I6*G6 (copy to J7:J14)											
30	K6		=C6-I6 (copy to K7:K14)											

Figure 16: Excel Spreadsheet for crash problem, 47-Day Solution and Cost

With the inputs as in Figure 13, *POM-QM for Windows 3* can generate crashing results as depicted in Figure 17. *MS Project 2007* will be able to do this on individual resource level but not on the activity level. This is regarded as difficult for beginners [1].

	Normal time	Crash time	Normal Cost	Crash Cost	Crash cost/ptd	Crash by	Crashing cost
Project	51	47					0
1-2	16	12	800	1,200	100	0	0
1-3	20	18	1,200	1,400	100	2	200
1-11	30	27	600	900	100	0	0
2-8	15	14	450	450	0	0	0
3-7	15	14	420	480	60	1	60
3-8	10	9	400	500	100	0	0
7-8	3	3	900	900	0	0	0
7-11	16	15	320	480	160	1	160
8-11	12	11	600	720	120	0	0
TOTALS			5,690				420

Figure 17: Crashing results using POM-QM for Windows 3

VIII. DISCUSSIONS

In order to decide which software package is better for the module, a pseudo quantity evaluation method is employed, in which scores are allocated to each package when it satisfies a particular objective of the topic. Score of 0 to 10 will be awarded to each package for satisfying a particular objective, 10 being the highest and the package with highest total scores is considered to be more suitable software for the module.

For constructing network diagram (objective 2), *Excel* should score zero. The other two packages should score 7 because they are not very good at this. However, they can

meet the desired outcome as learners can draw the CPA network diagram.

Excel can be used to evaluate the earliest start, earliest finish, latest start and latest finish times (objective 3), and calculate the total, free and independent floats (objective 4) for all activities and present them in a table as depicted in Figure 9. The programming techniques required is not too difficult for engineering students but students must have a very good grasp of the concept of objectives 3 and 4 before they can program the software. This is good in the sense that students have to learn the underlying principles and do not rely on software packages to obtain the results. *POM-QM for Windows 3* can be used to evaluate the earliest start, earliest finish, latest start and latest finish times, and calculate the total float for all activities and present them in a table. The package, however, was not able to evaluate the free and the independent floats. On the other hand, *MS Project 2007* cannot perform these functions. Only *Excel* and *POM-QM for Windows 3* can meet the requirements of objectives 3 and 4 of the topic; this matches the desired outcomes as students can evaluate the earliest start, earliest finish, latest start and latest finish times, and calculate float availability and present them in a table; these are in line with the desired outcomes as learners learn objectives 3 and 4.

In constructing Gantt chart, *Excel* can perform the work well but some programming technique is required. It can score 5 only because it cannot show critical path in the chart. Both packages, *MS Project 2007* and *POM-QM for Windows 3* can create Gantt chart but *POM-QM for Windows 3* can do better because it shows the critical path in the Gantt chart without requiring further operation. All packages can meet the requirements of objective 5 of the topic; this matches the desired outcomes as students can draw Gantt chart.

In costing and crashing, *Excel* can do the work very well but the programming technique involved is difficult even for engineering students. Students must have a very good grasp of the concept of objective 6 (crashing) before they can program the package. This is good in the sense that students have to learn the underlying principles and do not rely on software packages to obtain the results. However, *POM-QM for Windows 3* is more suitable for beginners as it will be able to do crashing on an activity level but may not be so practical for practitioners. *MS Project 2007* is more practical as it can compare costs with changing inputs like normal and overtime hourly rates. It can cope with change at resource level and is nearer to a real life situation. Both can meet the requirements of objective 6 of the module; this matches the desired outcome as students can evaluate the most economic and/or the shortest possible time based on the information provided. Both packages, *MS Project 2007* and *POM-QM for Windows 3*, can perform the functions but *POM-QM for Windows 3* is better because it shows the critical path in the Gantt chart without requiring further operation. Again, both packages can satisfy objective 6 of the module; this matches the desired outcome as students can construct Gantt chart quickly and logically.

The addition of three software packages to the topics in the course will certainly improve the academic standing of the course because its contents are now at par with most of international textbooks. Students will also be able to apply what they have learnt from the course to their workplace

with ease as they will not need to do complicated iterations or calculations. All are done by standard software packages.

With reference to Table 3, it can be found that *POM-QM for Windows 3* (49) is still the best package for the module; *Excel* (42) comes next but it needs programming. The final one is *MS Project 2007* (27) given that it is relatively expensive and cannot perform some operations required by the seven objectives [1].

Table 3: Scores to the three software packages used

Factors considered	<i>POM-QM for Windows 3</i>	<i>MS Project 2007</i>	<i>Excel in MS Office 2007</i>
Objective 1	0	0	0
Objective 2	7	7	0
Objective 3	8	0	10
Objective 4	8	0	9
Objective 5	6	9	5
Objective 6	3	10	9
Objective 7	7	0	8
Price	10	1	1
Total scores	49	27	42

IX. CONCLUSION

For *critical path networks*, more than one package will be required; different packages will be required on different parts of the problem and no one package can satisfy the needs for beginners. For teaching the objectives of the critical path networks of ENG4004 Engineering Management Science, *POM-QM for Windows 3* is the best because it can meet all the objectives of the course except objective one and scores 49 in the comparison table. On the other hand, *Excel* is a very good package for learning because students cannot use it to meet the objectives of the module unless they have a very good grasp of the concepts of the objectives. *MS Project 2007* is an excellent package in practice because of its resource leveling capability, but for teaching it is not as good as the other two packages.

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