



GuideMyGrades

— YOUR GOALS. OUR EXPERTISE. —

EDEXCEL INTERNATIONAL A LEVEL MATHS: QUESTIONS BY TOPIC

Critical Path Analysis (D1.4)

International A Level Mathematics · D1: Decision Mathematics 1 (WDM11)

24 questions · 239 marks · Mark schemes included

Past papers June 2019 - June 2025 · 1 sub-topic

 guidemygrades.com

 [@Guidemygrades](https://www.instagram.com/Guidemygrades)

 [@Guidemygrades](https://twitter.com/Guidemygrades)

 [@Guidemygrades](https://www.youtube.com/Guidemygrades)

 info@guidemygrades.com

 Piccadilly Business Centre, Unit C, Aldow Enterprise Park
Blackett Street, Manchester, M12 6AE

HOW TO USE THIS BOOKLET

Questions are grouped by sub-topic and run from the lowest to the highest mark tariff, then oldest paper first.

Click any row below to jump straight to that sub-topic or question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme; < QUESTION brings you back.

A gold bar in the left margin marks exactly where the question sits on the original page.

Where a question is answered in a separate answer book, those answer book pages follow the question.

Each question is filed under its main topic; longer questions may also test skills from other topics.

QUESTION	SOURCE	MARKS	PAGE
D1.4a	ACTIVITY NETWORKS, CRITICAL PATHS & SCHEDULING	24 Qs · 239 marks	2
1. Q3	IAL D1 (WDM11) January 2022	5	3
2. Q4	IAL D1 (WDM11) January 2025	6	6
3. Q5	IAL D1 (WDM11) January 2020	7	9
4. Q4	IAL D1 (WDM11) October 2020	7	19
5. Q5	IAL D1 (WDM11) June 2023	7	22
6. Q4	IAL D1 (WDM11) January 2024	7	25
7. Q6	IAL D1 (WDM11) June 2019	8	28
8. Q3	IAL D1 (WDM11) January 2020	9	32
9. Q6	IAL D1 (WDM11) June 2021	9	35
10. Q5	IAL D1 (WDM11) June 2022	9	36
11. Q2	IAL D1 (WDM11) June 2021	10	39
12. Q4	IAL D1 (WDM11) January 2022	10	42
13. Q1	IAL D1 (WDM11) June 2023	10	45
14. Q2	IAL D1 (WDM11) June 2024	10	48
15. Q6	IAL D1 (WDM11) June 2024	10	51
16. Q4	IAL D1 (WDM11) October 2021	11	55
17. Q2	IAL D1 (WDM11) June 2022	11	59
18. Q4	IAL D1 (WDM11) June 2019	12	62
19. Q5	IAL D1 (WDM11) October 2020	12	65
20. Q6	IAL D1 (WDM11) January 2021	13	68
21. Q4	IAL D1 (WDM11) January 2023	13	72
22. Q1	IAL D1 (WDM11) January 2024	13	75
23. Q7	IAL D1 (WDM11) January 2025	14	78
24. Q7	IAL D1 (WDM11) June 2025	16	81



QUESTIONS

24 questions · 239 marks · 1 sub-topic

SUB-TOPIC D1.4a

ACTIVITY NETWORKS, CRITICAL PATHS & SCHEDULING

Sub-topic D1.4a · 24 questions · 239 marks · lowest tariff first



3.

Activity	Immediately preceding activities
A	–
B	–
C	–
D	A, B, C
E	A, B, C
F	C
G	F
H	D
I	D, E, G
J	D, E

Draw the activity network described in the precedence table above, using activity on arc and exactly 4 dummies.

(5)

(Total 5 marks)



3.

Activity	Immediately preceding activities
A	–
B	–
C	–
D	A, B, C
E	A, B, C
F	C
G	F
H	D
I	D, E, G
J	D, E



Question 3 continued

Please redraw your activity network on this page if you need to do so.

(Total 5 marks)



4.

Activity	Immediately preceding activities
A	-
B	-
C	-
D	A
E	A, B, C
F	A, B, C
G	C
H	D, E, F
I	F
J	F, G
K	F, G

- (a) Draw the activity network described in the precedence table above, using activity on arc and the minimum number of dummies.

(5)

Given that

- activity D has a duration of 2 hours
- activity I has a duration of 2 hours
- every other activity has a duration of 1 hour
- D and I are critical activities

- (b) determine which other activities are critical.

(1)

(Total for Question 4 is 6 marks)



4.



Question 4 continued

(Total for Question 4 is 6 marks)



5.

Activity	Immediately preceding activities
A	–
B	–
C	–
D	A
E	C
F	A, B, C
G	A, B, C
H	D, F, G
I	A, B, C
J	D, F, G
K	H
L	D, E, F, G, I

- (a) Draw the activity network described in the precedence table above, using activity on arc. Your activity network must contain only the minimum number of dummies. (5)

Given that all critical paths for the network include activity H,

- (b) state which activities cannot be critical. (2)

(Total 7 marks)



5.

Leave
blank

Question 5 continued

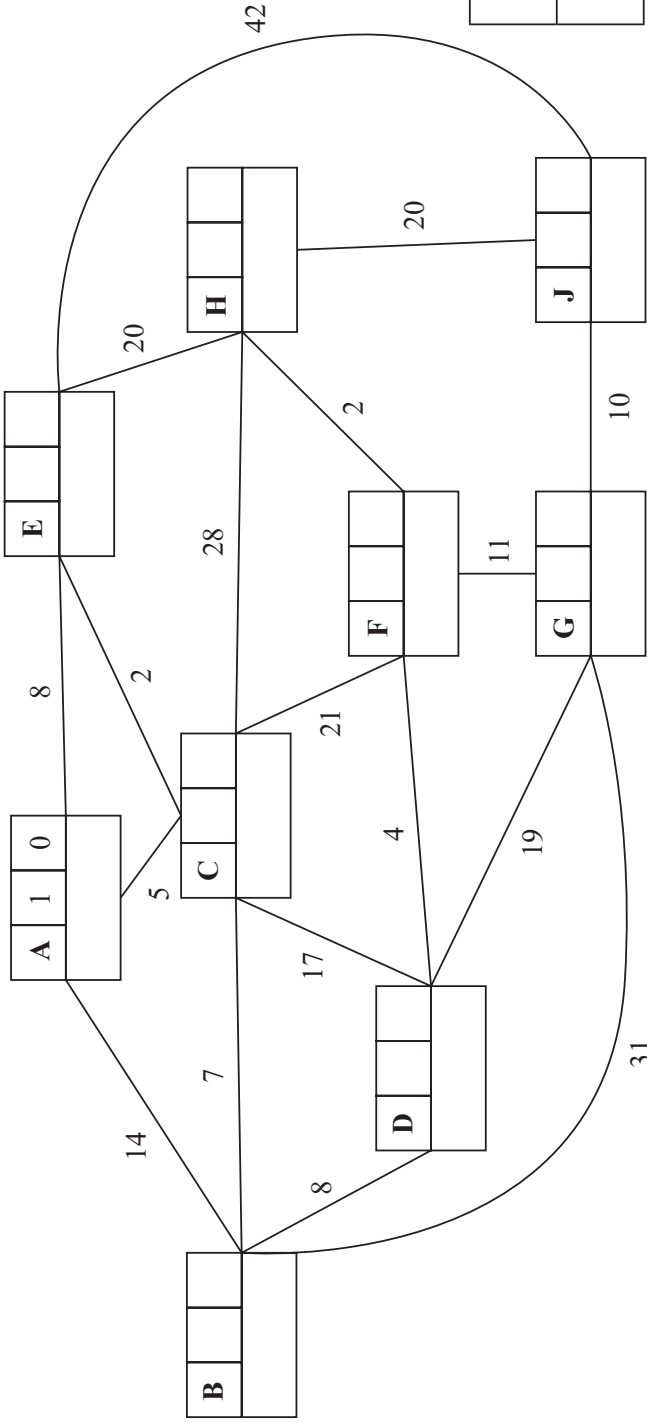
Leave
blank

Q5

(Total 7 marks)



6.



Shortest time: _____

Quickest route: _____

Leave blank



Question 6 continued

Leave
blank



Question 6 continued

Leave
blank

Handwriting practice lines for Question 6.

(Total 15 marks)

Q6

--	--



7.

Leave
blank



Question 7 continued

Leave
blank



Question 7 continued

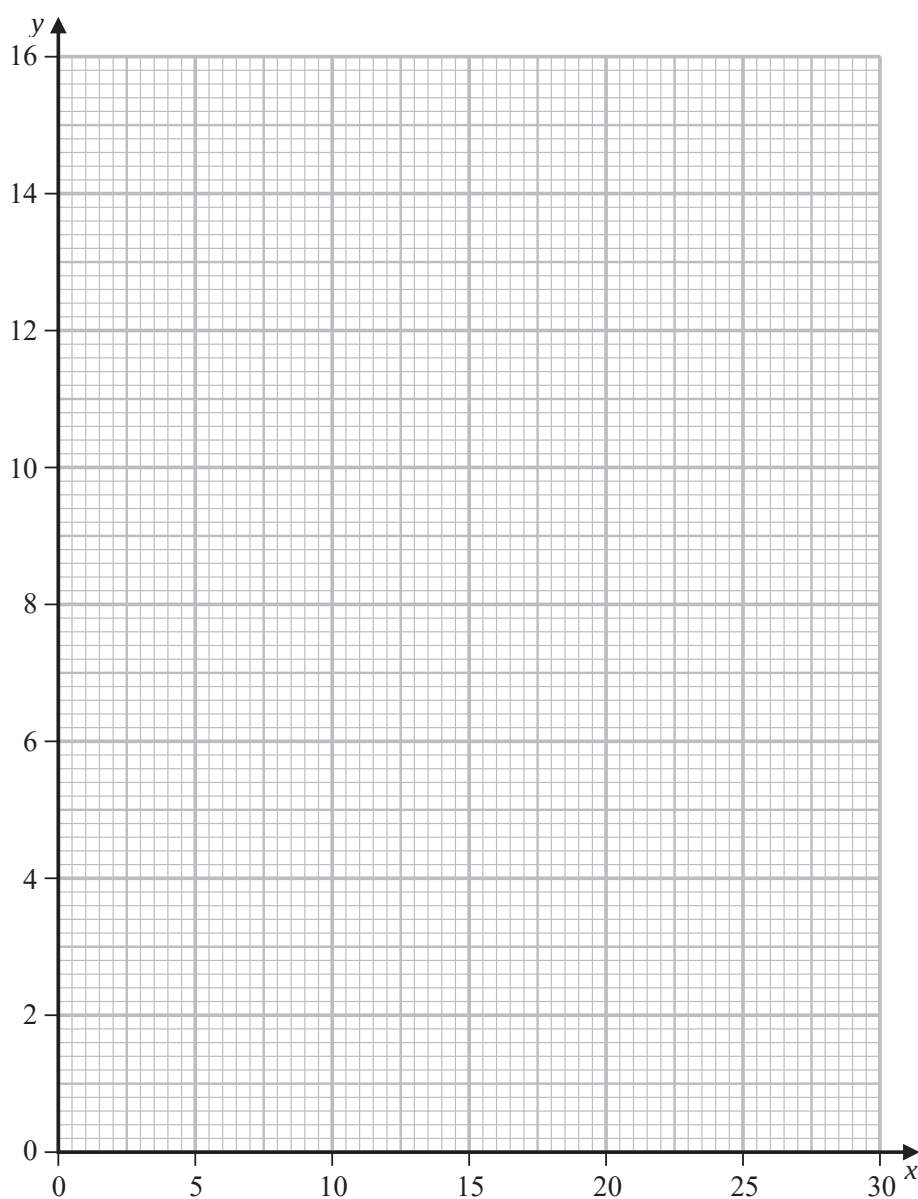
Leave
blank

Diagram 1



Question 7 continued

Leave
blank

Q7

(Total 18 marks)

TOTAL FOR PAPER: 75 MARKS

END



4. (a) Draw the activity network described by the precedence table below, using activity on arc. Use dummies only where necessary.

(5)

Activity	Immediately preceding activities
A	—
B	—
C	A
D	A, B
E	C, D
F	D
G	C
H	G
I	G
J	E, F, I
K	F

Given that K is a critical activity,

- (b) state which other activities must also be critical.

(1)

Given instead that all activities shown in the precedence table have the same duration and K is not necessarily critical,

- (c) state the critical path for the network.

(1)

(Total 7 marks)



4.

Leave
blank

Question 4 continued

Leave
blank

Q4

(Total 7 marks)



5.

Activity	Immediately preceding activities
A	-
B	-
C	-
D	A
E	A
F	B, C, E
G	B, C, E
H	C
I	C
J	D, F, G, H, I
K	D, F, G, H, I
L	I

- (a) Draw the activity network described in the precedence table above, using activity on arc and the minimum number of dummies.

(5)

A project is modelled by the activity network drawn in (a). Each activity requires exactly one worker. The project is to be completed in the shortest possible time. The table below gives the time, in hours, to complete three of the activities.

Activity	Duration (in hours)
A	10
E	7
F	8

The length of the critical path AEFK is 33 hours.

- (b) Determine the range of possible values for the duration of activity J. You must make your method and working clear.

(2)

(Total for Question 5 is 7 marks)



5.



Question 5 continued

(Total for Question 5 is 7 marks)



4.

Activity	Immediately preceding activities
A	—
B	—
C	A, B
D	A, B
E	B
F	C, D, E
G	F
H	B
I	F
J	F
K	G
L	G, H, I, J
M	G, I

- (a) Draw the activity network described in the precedence table, using activity on arc and the minimum number of dummies.

(5)

- (b) Given that

- the activity network contains only one critical path
- activity E is on this critical path

state

- which activities could **never** be critical,
- which activities **must** be critical.

(2)

(Total for Question 4 is 7 marks)



4.



Question 4 continued

Only use this blank space if you need to redraw your activity network.

(Total for Question 4 is 7 marks)



6.

Activity	Immediately preceding activities
A	–
B	–
C	–
D	–
E	A
F	A, B, C
G	C
H	C
I	D, H
J	E
K	E
L	F, G, I
M	G, I

- (a) Draw the activity network described in the precedence table, using activity on arc and exactly four dummies.

(5)

Given that there is a unique critical path for the network and that K is a critical activity,

- (b) state the critical path for the network.

(1)

Given instead that all the activities shown in the precedence table have the same duration and K is not necessarily critical,

- (c) state all the possible critical paths for the network.

(2)

(Total 8 marks)

TOTAL FOR PAPER: 75 MARKS
END

6.

Leave
blank

Question 6 continued

Leave
blank

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

Question 6 continued

Leave
blank

(Total 8 marks)

Q6

TOTAL FOR PAPER: 75 MARKS

END



3.

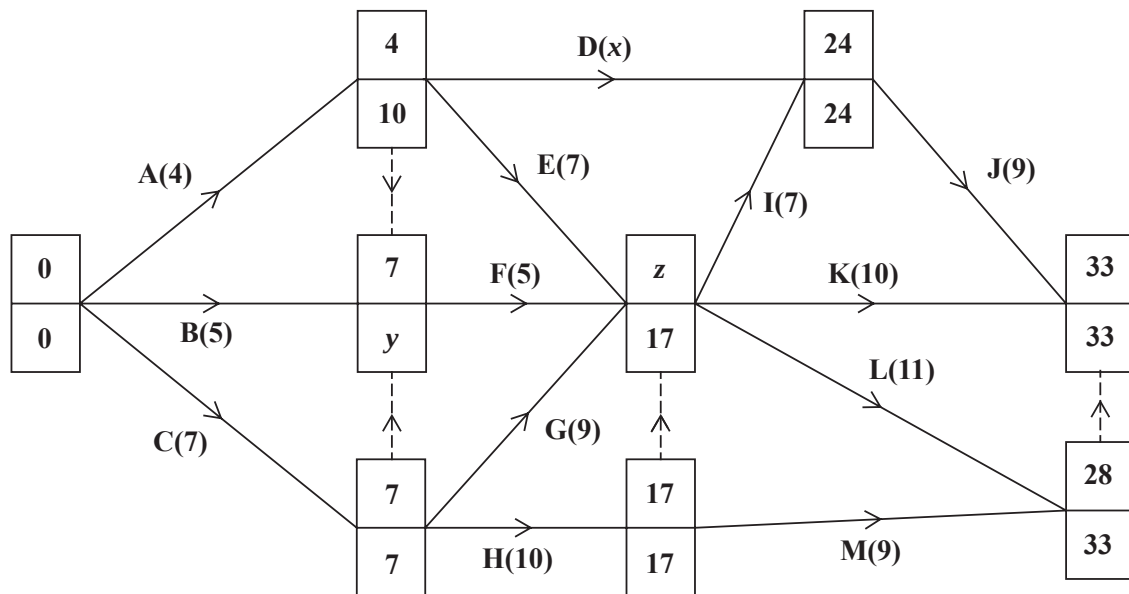


Figure 2

The network in Figure 2 shows the activities that need to be undertaken by a company to complete a project. Each activity is represented by an arc and the duration, in days, is shown in brackets. Each activity requires one worker. The early event times and late event times are shown at each vertex.

The total float on activity D is twice the total float on activity E.

- Find the values of x , y and z . (3)
- Draw a cascade chart for this project on Grid 1 in the answer book. (4)
- Use your cascade chart to determine a lower bound for the minimum number of workers needed to complete the project in the shortest possible time. You must make specific reference to time and activities. (You do not need to provide a schedule of the activities.) (2)

(Total 9 marks)

3.

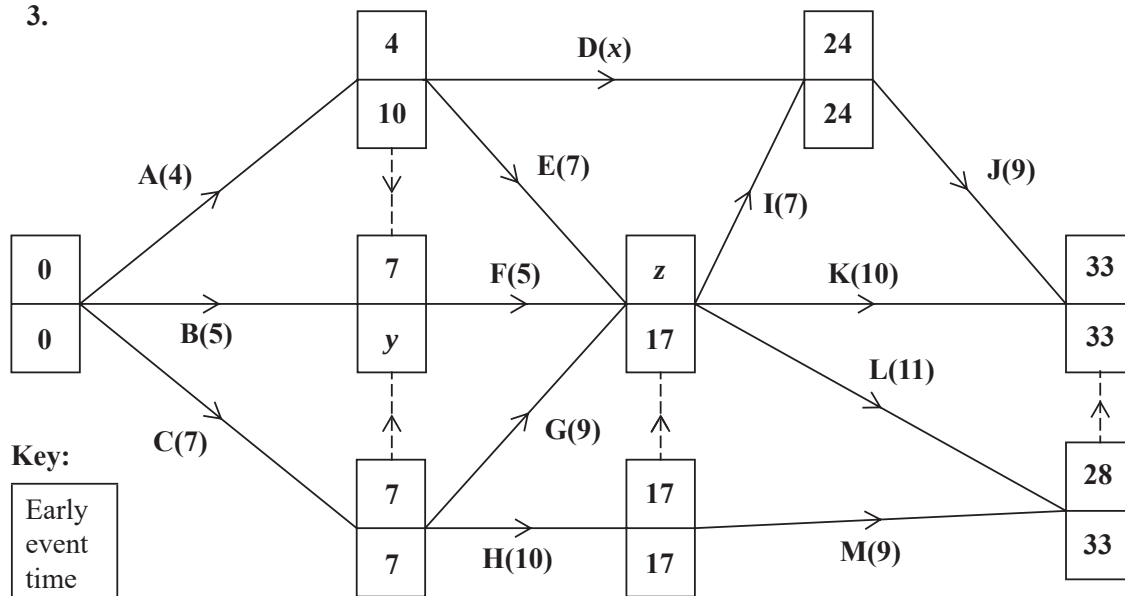
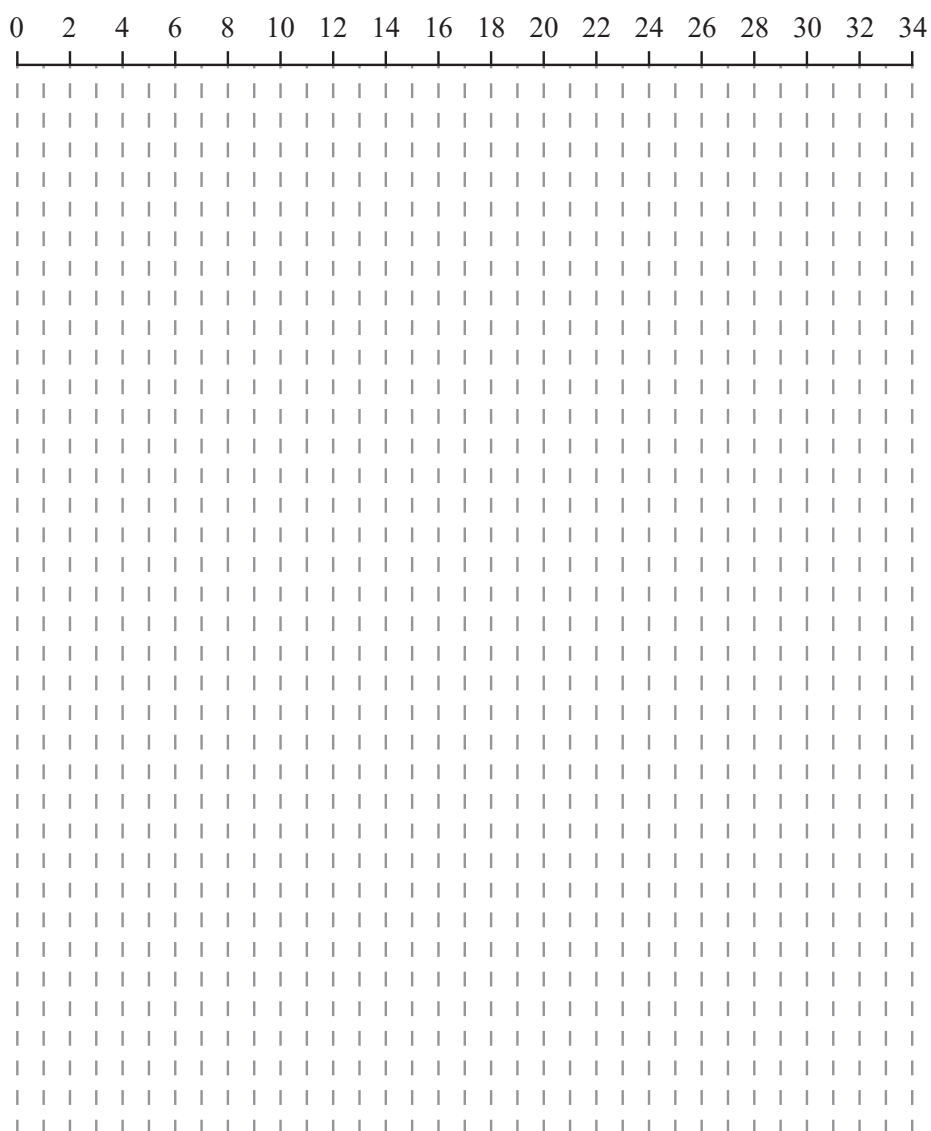


Figure 2

Leave blank

Question 3 continued

Leave
blank



Grid 1

[illegible]

(Total 9 marks)

Q3



6.

Activity	Immediately preceding activities
A	–
B	–
C	–
D	A
E	A
F	A, B, C
G	C
H	G
I	D, E, F, H
J	I
K	I
L	I
M	L

- (a) Draw the activity network for the project described in the precedence table above, using activity on arc and the minimum number of dummies. (5)

- (b) State which activity is guaranteed to be critical, giving a reason for your answer. (2)

It is given that each activity in the table takes two hours to complete.

- (c) State the minimum completion time and write down the critical path for the project. (2)

(Total 9 marks)



5. The precedence table shows the eleven activities required to complete a project.

Activity	Immediately preceding activities
A	—
B	—
C	—
D	A, B
E	A, B
F	B, C
G	B, C
H	D
I	D, E, F, G
J	H, I
K	D, E, F

(a) Draw the activity network for the project, using activity on arc and the minimum number of dummies.

(5)

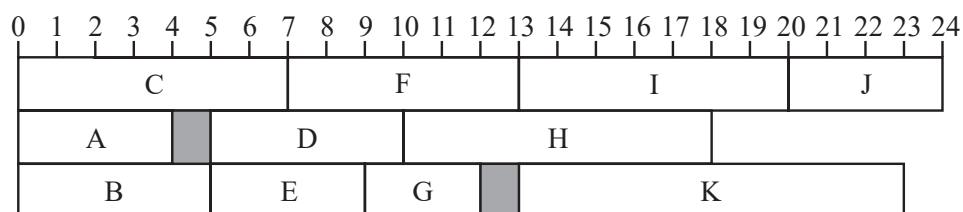


Figure 3

Figure 3 shows a schedule for the project. Each of the activities shown in the precedence table requires one worker. The time taken to complete each activity is in hours and the project is to be completed in the minimum possible time.

(b) (i) State the minimum completion time for the project.

(ii) State the critical activities.

(iii) State the total float on activity G and the total float on activity K.

(4)

(Total for Question 5 is 9 marks)

5.

Activity	Immediately preceding activities
A	–
B	–
C	–
D	A, B
E	A, B
F	B, C
G	B, C
H	D
I	D, E, F, G
J	H, I
K	D, E, F



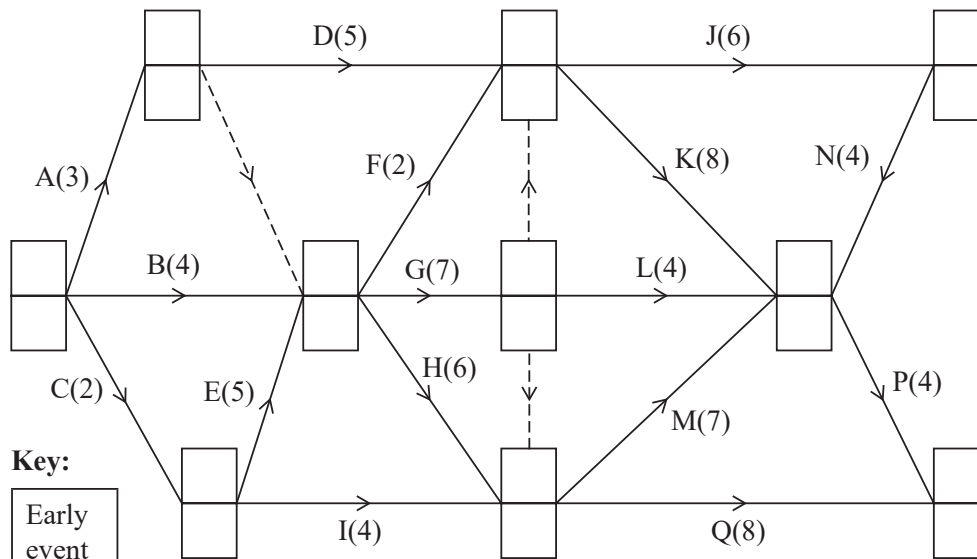
Question 5 continued

Please redraw your activity network on this page if you need to do so.

(Total for Question 5 is 9 marks)

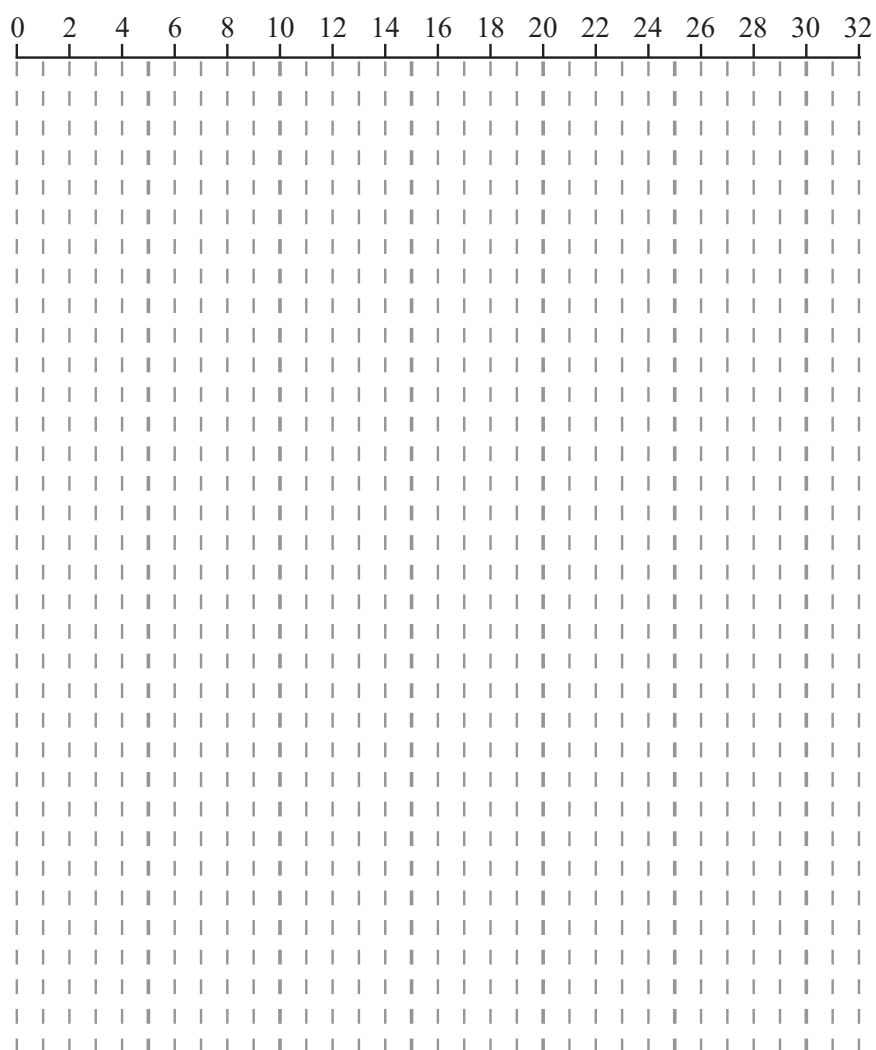


2.

**Key:**Early
event
timeLate
event
time**Diagram 1**Leave
blank

Question 2 continued

Leave
blank



Grid 1

[illegible]

(Total 10 marks)

Q2



4.

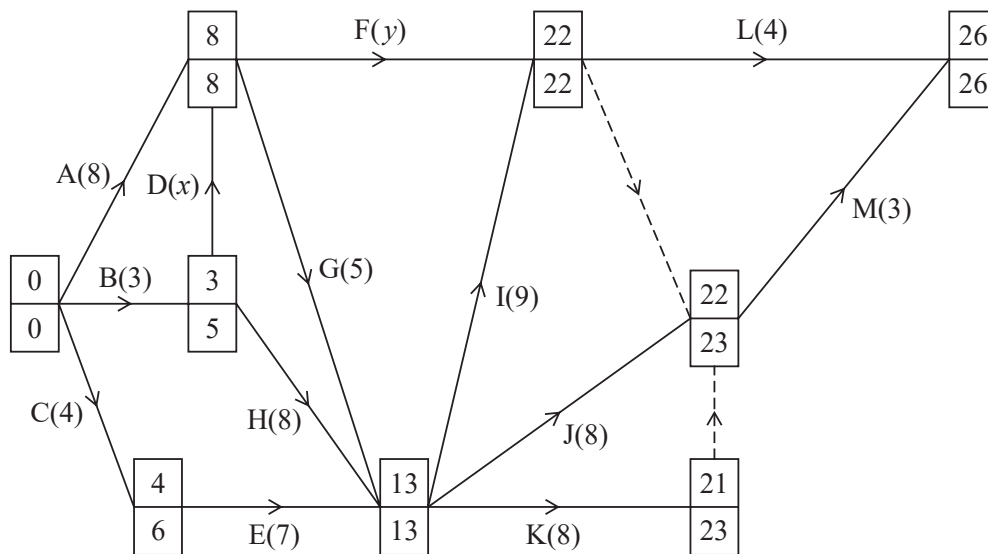


Figure 3

The network in Figure 3 shows the activities that need to be undertaken by a company to complete a project. Each activity is represented by an arc. The duration of the activity, in days, is shown in brackets. Each activity requires exactly one worker. The early event times and the late event times are shown at the vertices.

It is given that the total float on activity F is twice the total float on activity D.

It is also given that the total duration of the activities on the path BDFM is 10 days less than the duration of the critical path.

- (a) Determine the value of x and the value of y . You must make your method and working clear.

(4)

- (b) Draw a cascade chart for this project on Grid 1 in the answer book.

(4)

- (c) Use your cascade chart to determine the minimum number of workers needed to complete the project in the shortest possible time. You must make specific reference to time and activities. (You do not need to provide a schedule of the activities.)

(2)

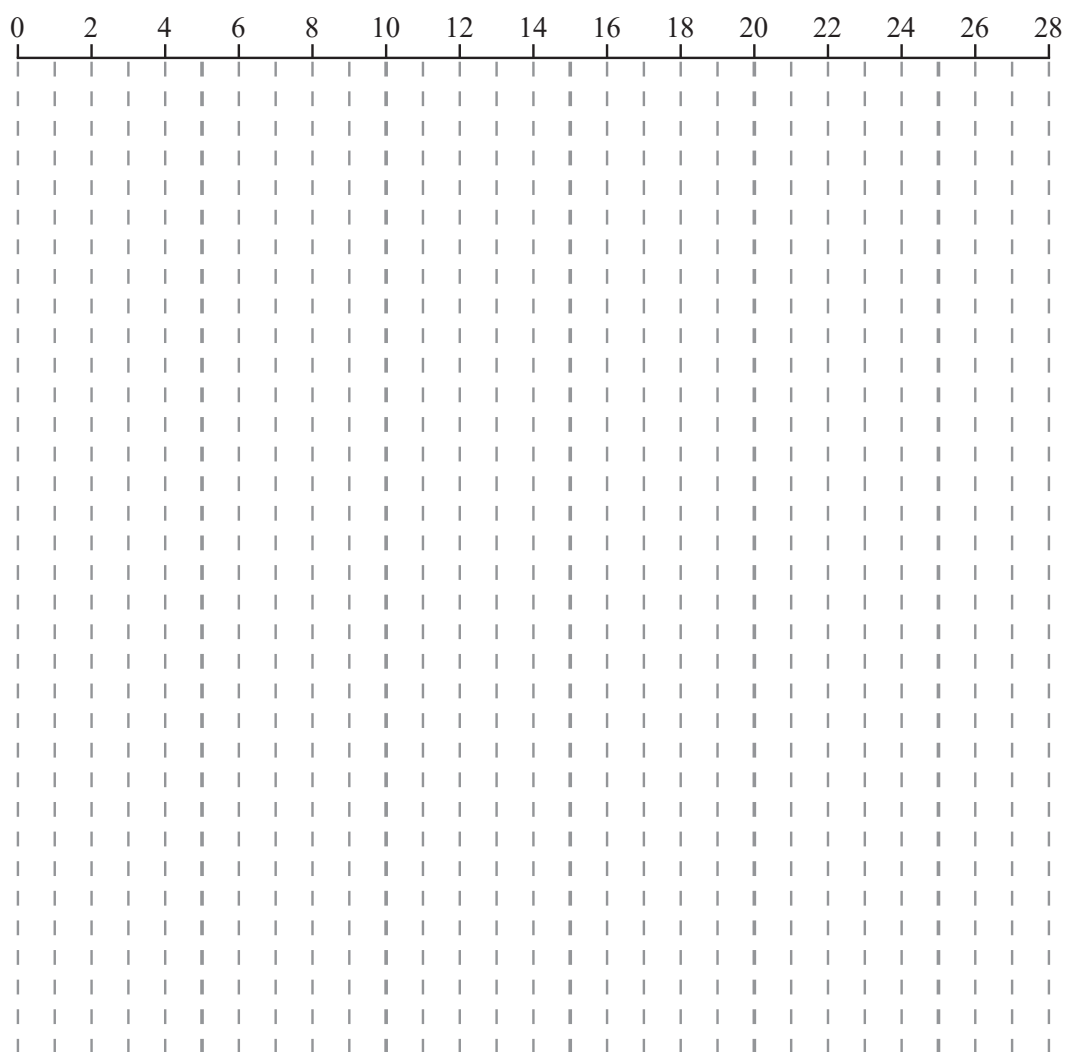
(Total 10 marks)

4.

Lined area for writing the answer to question 4.



Question 4 continued



Grid 1

Write your answers in the D1 answer book for this paper.

1.

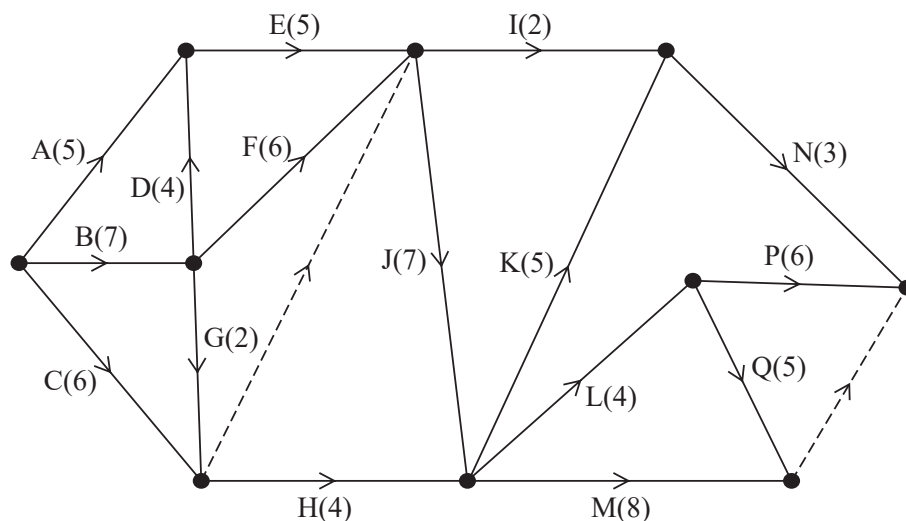


Figure 1

A project is modelled by the activity network shown in Figure 1. The activities are represented by the arcs. The number in brackets on each arc gives the time, in days, to complete the activity. Each activity requires exactly one worker. The project is to be completed in the shortest possible time.

- Complete Diagram 1 in the answer book to show the early event times and the late event times. (4)
- Calculate the maximum number of days by which activity H could be delayed without lengthening the completion time of the project. You must make the numbers used in your calculation clear. (1)
- Calculate a lower bound for the number of workers needed to complete the project in the minimum time. You must show your working. (2)
- Schedule the activities on Grid 1 in the answer book, using the minimum number of workers, so that the project is completed in the minimum time. (3)

(Total for Question 1 is 10 marks)

1.

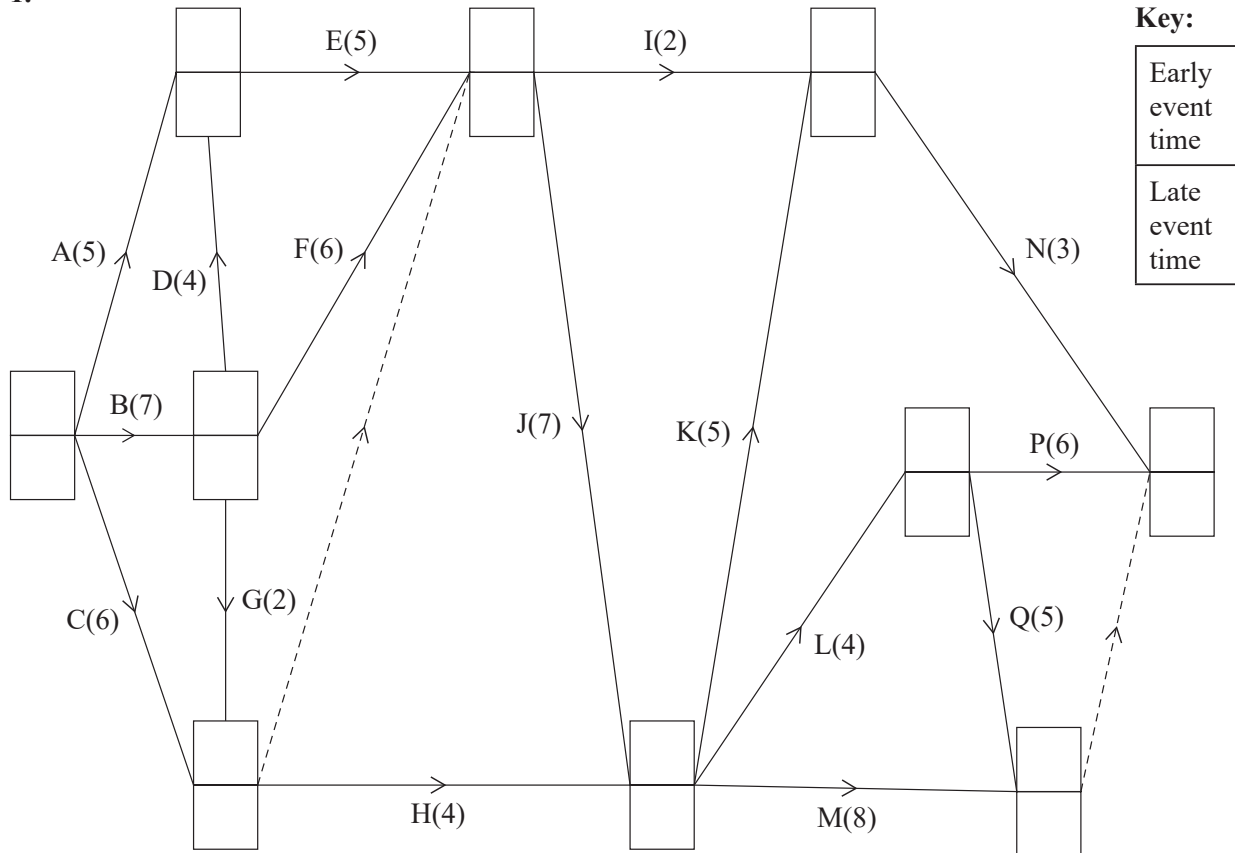
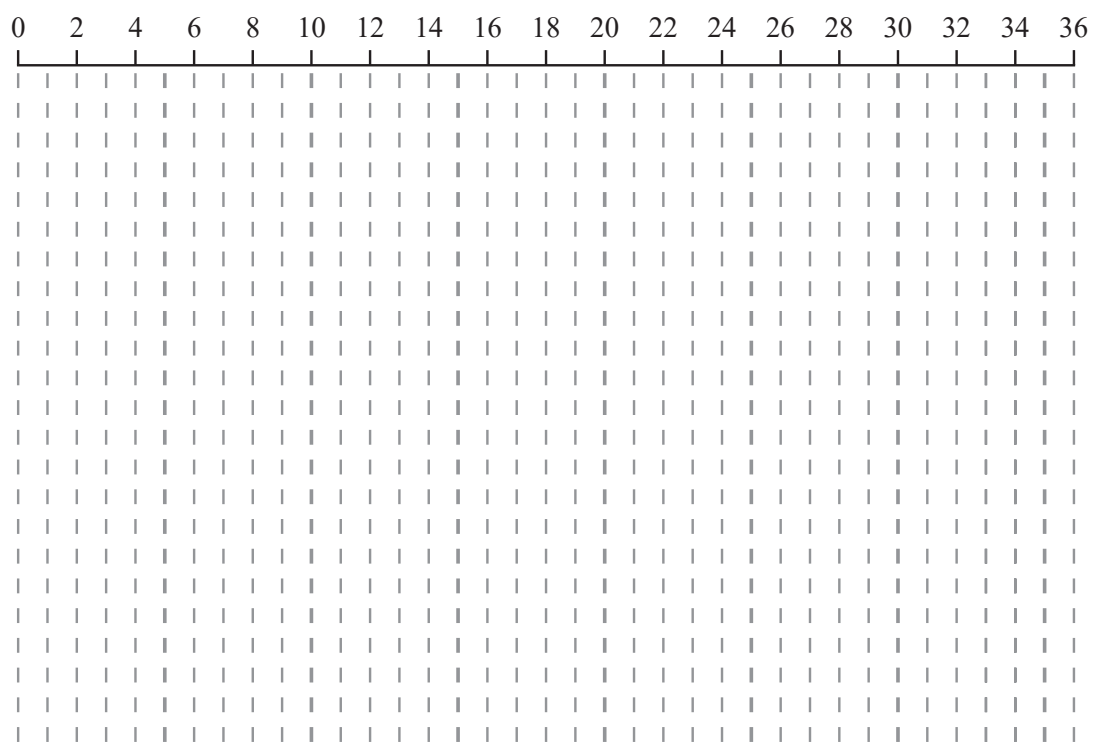


Diagram 1

Question 1 continued



Grid 1

(Total for Question 1 is 10 marks)



2.

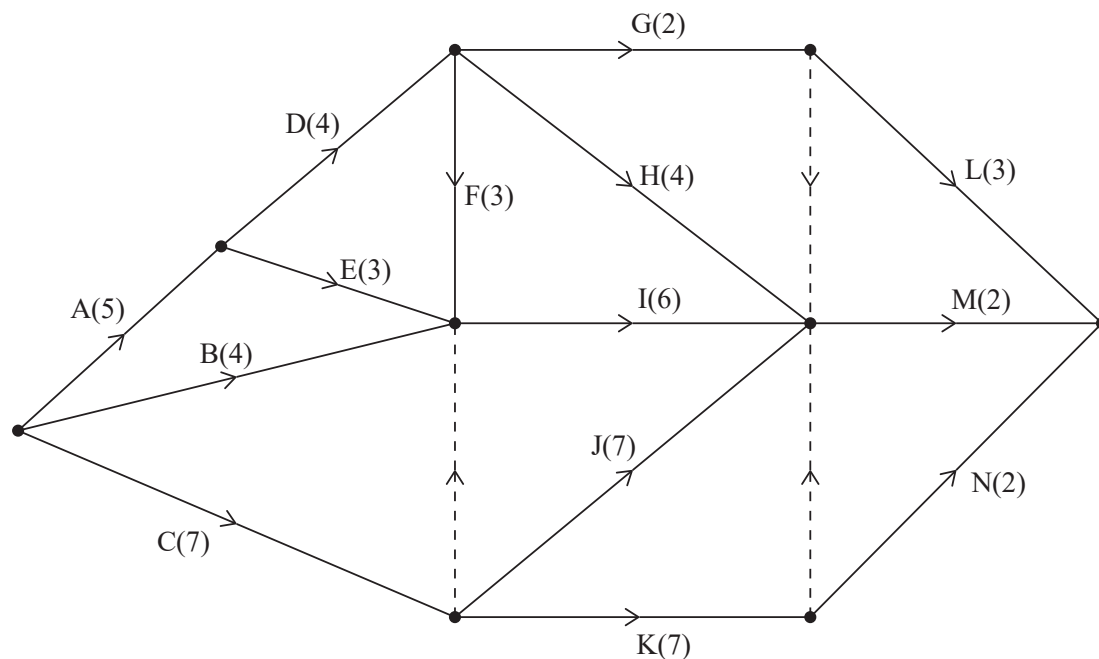


Figure 1

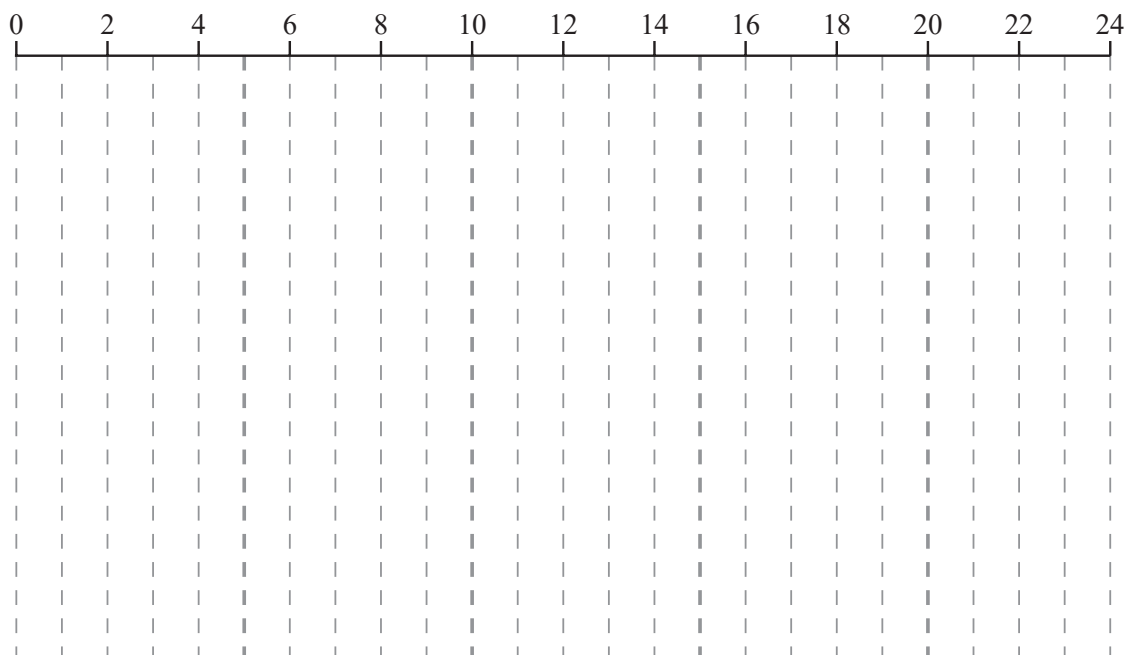
[The sum of the durations of all the activities is 59 days.]

The network in Figure 1 shows the activities that need to be undertaken to complete a project. Each activity is represented by an arc and the duration, in days, of the corresponding activity is shown in brackets. Each activity requires one worker. The project is to be completed in the shortest possible time.

- (a) (i) Complete Diagram 1 in the answer book to show the early event times and the late event times.
- (ii) State the minimum completion time of the project. (5)
- (b) Calculate a lower bound for the number of workers needed to complete the project in the minimum time. You must show your working. (1)
- (c) Schedule the activities using the minimum number of workers so that the project is completed in the minimum time. (4)

(Total for Question 2 is 10 marks)

Question 2 continued



(Total for Question 2 is 10 marks)

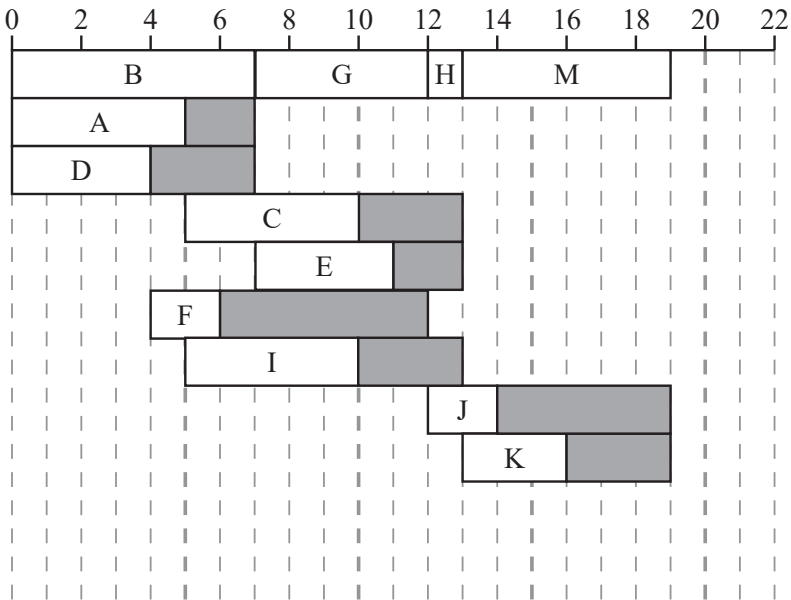


6.

Activity	Immediately preceding activities
A	-
B	-
C	A
D	-
E	A, B, D
F	D
G	A, B, D
H	F, G
I	A
J	F, G
K	C, E, H, I
L	I
M	C, E, H, I

(a) Draw the activity network for the project described in the precedence table, using activity on arc and the minimum number of dummies.

(5)



Grid 1



A cascade chart for all the activities of the project, **except activity L**, is shown on Grid 1.

The time taken to complete each activity is given in hours and each activity requires one worker.

The project is to be completed in the minimum time using as few workers as possible.

- (b) State the critical activities of the project. (1)
- (c) Use the cascade chart to determine the minimum number of workers needed to complete the project in the shortest possible time. You must make specific reference to time and activities. (You do **not** need to provide a schedule of the activities.) (2)

The duration of activity L is x hours. Given that the total float of activity L is at most 7 hours,

- (d) determine the range of possible values for x . (2)

(Total for Question 6 is 10 marks)



6.



Question 6 continued

(Total for Question 6 is 10 marks)



4.

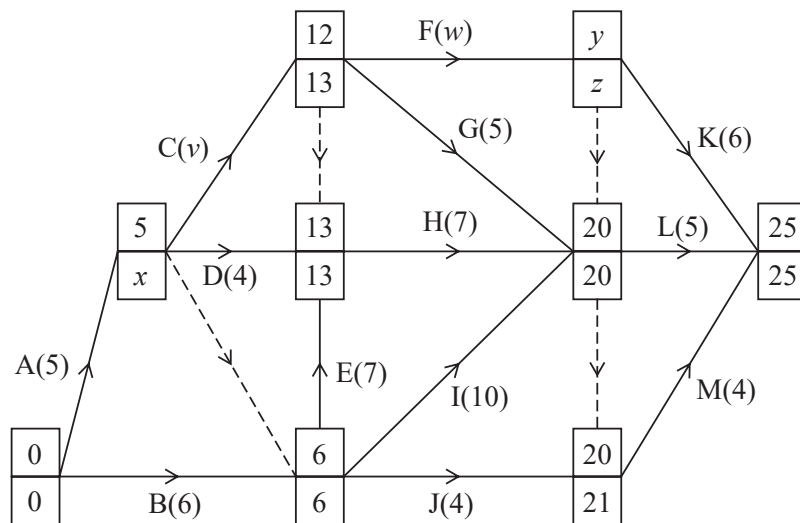


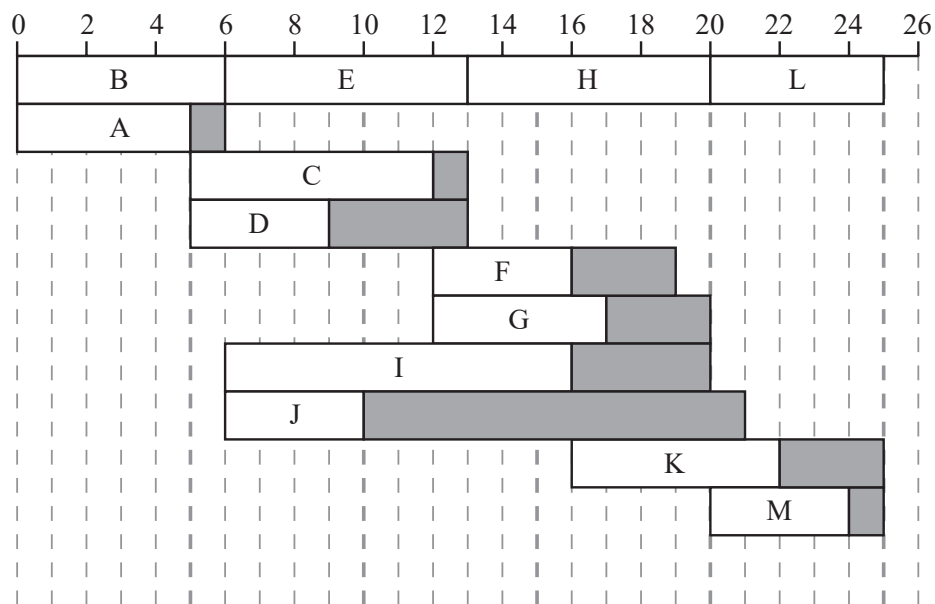
Figure 2

The network in Figure 2 shows the activities that need to be carried out by a company to complete a project. Each activity is represented by an arc, and the duration, in days, is shown in brackets. Each activity requires one worker. The early event times and the late event times are shown at each vertex.

(a) Complete the precedence table in the answer book.

(2)

A cascade chart for this project is shown on Grid 1.



Grid 1

(b) Use Figure 2 and Grid 1 to find the values of v , w , x , y and z .

(3)

The project is to be completed in the minimum time using as few workers as possible.

(c) Calculate a lower bound for the minimum number of workers required. You must show your working.

(1)

(d) On Grid 2 in your answer book, construct a scheduling diagram for this project.

(3)

Before the project begins it is found that activity F will require an additional 5 hours to complete. The durations of all other activities are unchanged. The project is still to be completed in the shortest possible time using as few workers as possible.

(e) State the new minimum project completion time and state the new critical path.

(2)

(Total 11 marks)

4.

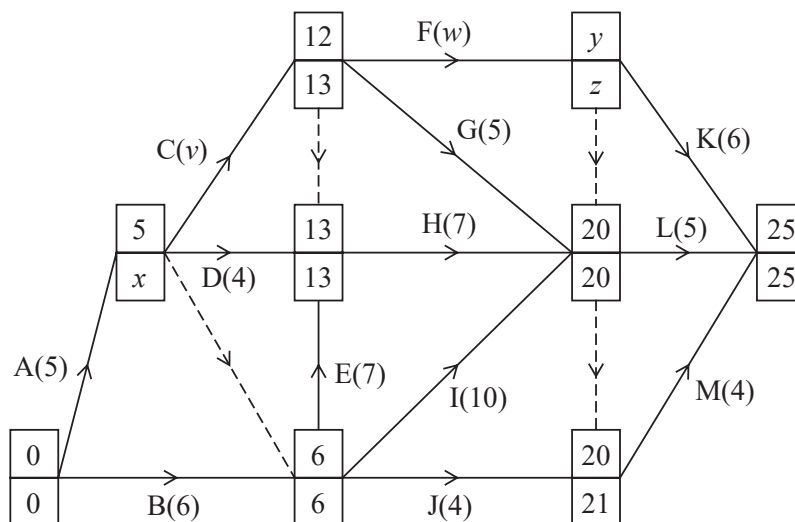
Leave
blank

Figure 2

(a)

Activity	Immediately preceding activities
A	
B	
C	
D	
E	

Activity	Immediately preceding activities
F	
G	
H	
I	
J	

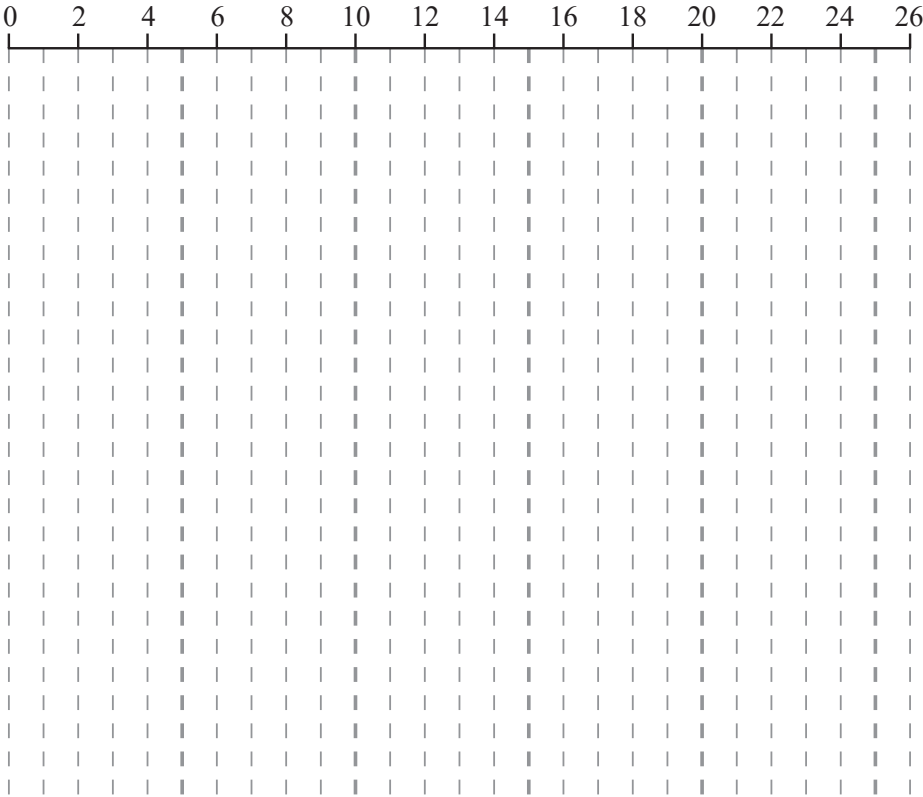
Activity	Immediately preceding activities
K	
L	
M	

$v =$ _____ $w =$ _____ $x =$ _____ $y =$ _____ $z =$ _____



Question 4 continued

Leave
blank



Grid 2

Handwriting practice area consisting of 15 horizontal lines.

(Total 11 marks)

Q4

Two small empty boxes for marking the question score.



2.

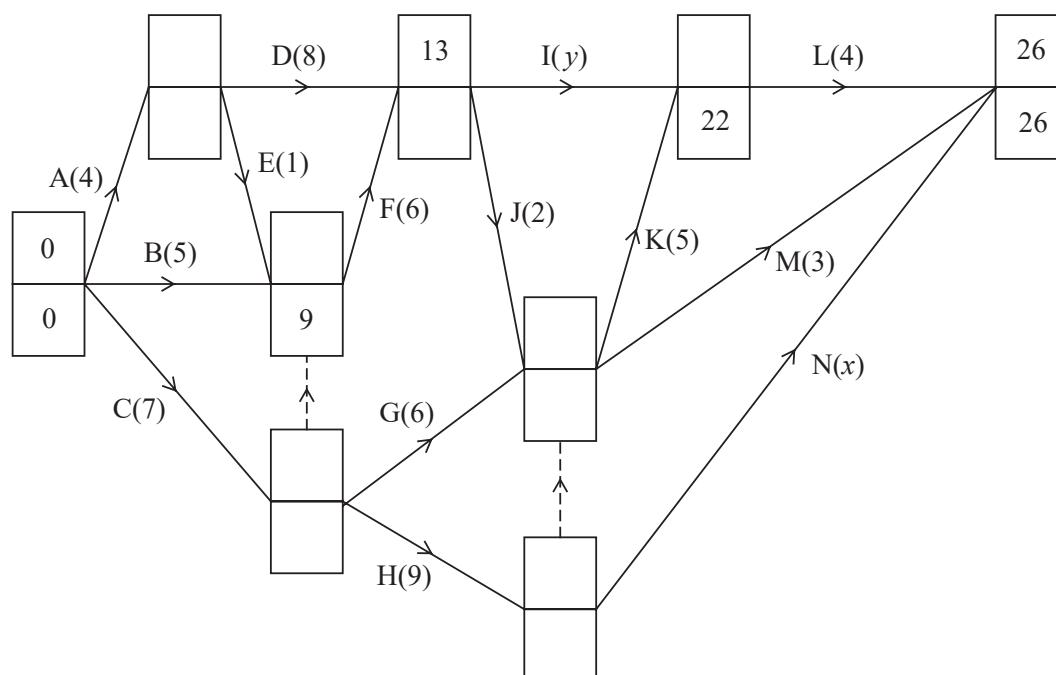


Figure 1

The network in Figure 1 shows the activities that need to be undertaken to complete a project. Each activity is represented by an arc and the duration of the activity, in days, is shown in brackets. The early event times and late event times are to be shown at each vertex and some have been completed.

Given that

- CHN is the critical path for the project
- the total float on activity B is twice the duration of the total float on activity I

(a) find the value of x and show that the value of y is 7

(2)

(b) Calculate the missing early event times and late event times and hence complete Diagram 1 in your answer book.

(3)

Each activity requires one worker, and the project must be completed in the shortest possible time.

(c) Draw a cascade chart for this project on Grid 1 in your answer book, and use it to determine the minimum number of workers needed to complete the project in the shortest possible time. You must make specific reference to time and activities.

(6)

(Total for Question 2 is 11 marks)



2.

(a)

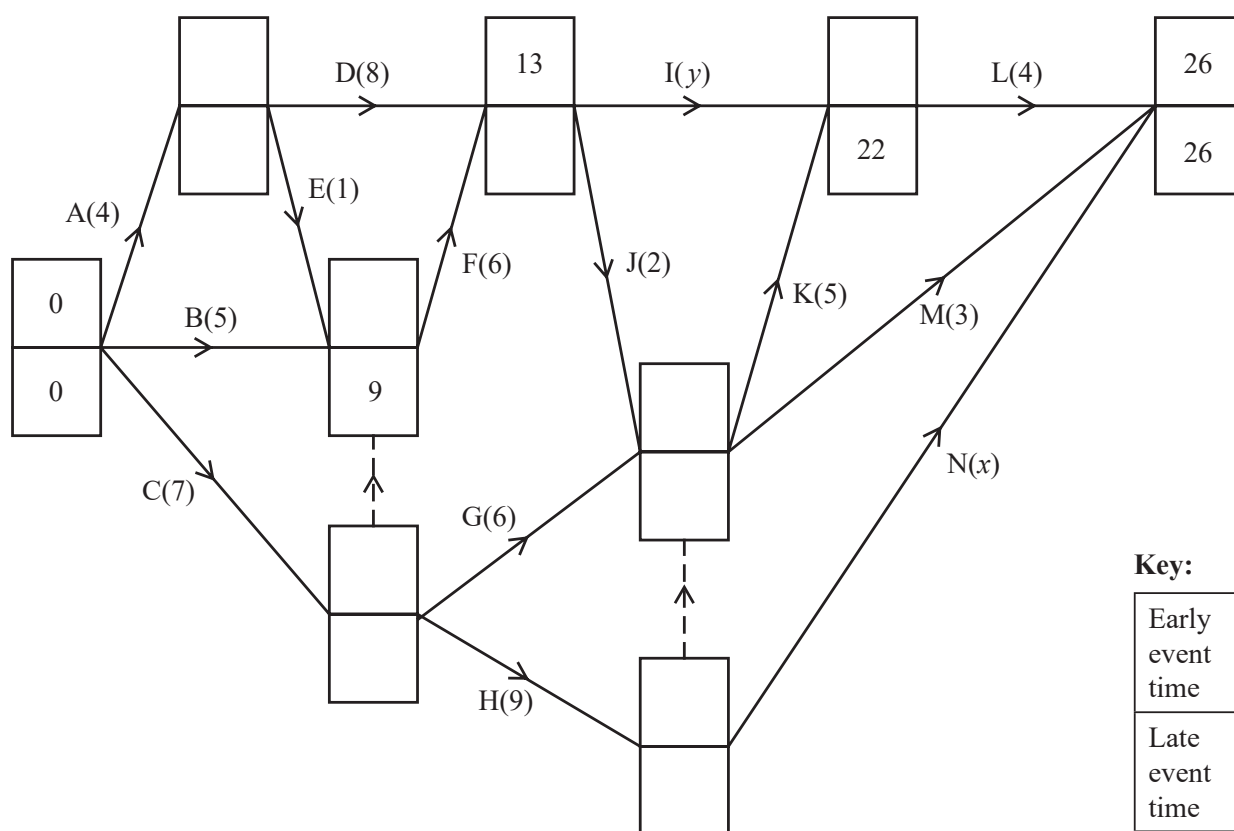


Diagram 1

Question 2 continued

A horizontal number line starting at 0 and ending at 26. Major tick marks are labeled with integers from 0 to 26. Minor tick marks are present between each major tick mark, representing half-unit intervals.

Grid 1

4.

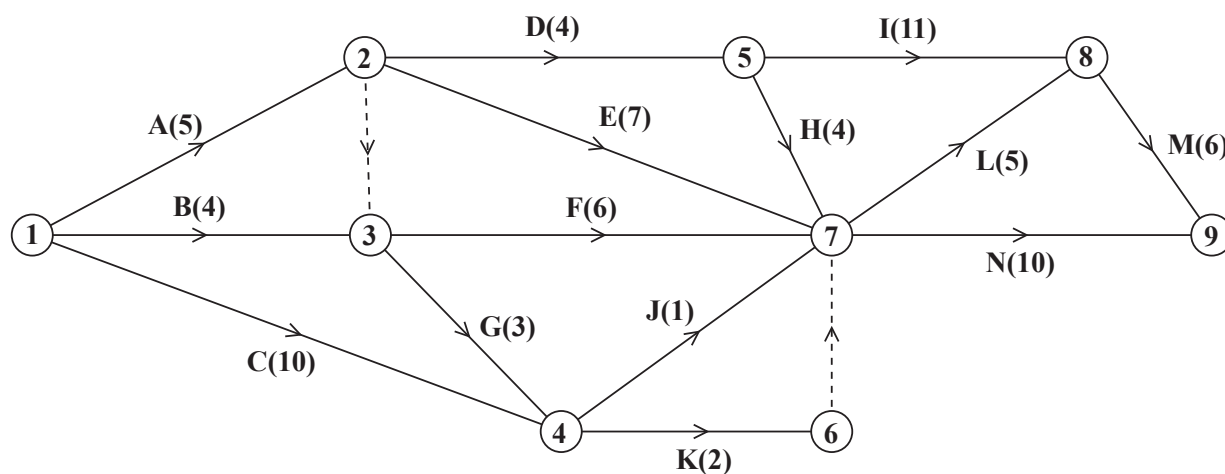


Figure 3

A project is modelled by the activity network shown in Figure 3. The activities are represented by the arcs. The number in brackets on each arc gives the time required, in hours, to complete the corresponding activity. The numbers in circles are the event numbers.

(a) Explain the significance of the dummy activity

(i) from event 2 to event 3

(ii) from event 6 to event 7

(2)

(b) Complete Diagram 1 in the answer book to show the early event times and the late event times.

(4)

(c) State the minimum project completion time and list the critical activities.

(2)

The duration of activity H changes to x hours.

(d) Find, in terms of x where necessary,

(i) the possible new early event time for event 7

(ii) the possible new late event time for event 7

(3)

Given that the duration of activity H is such that the minimum project completion time is four hours greater than the time found in (c),

(e) determine the value of x .

(1)

(Total 12 marks)



4.

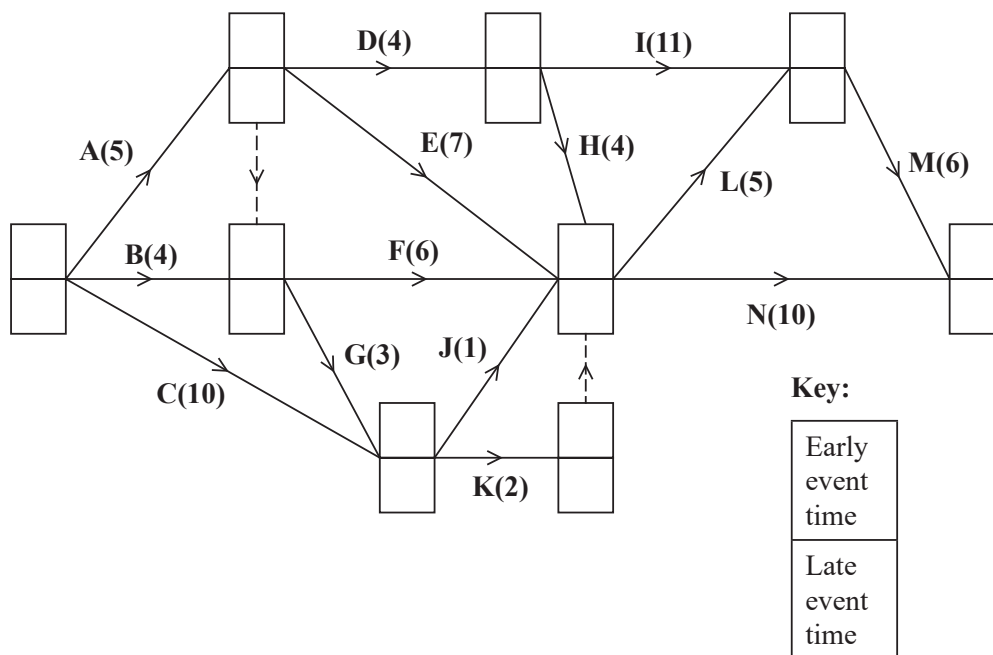
Leave
blank

Diagram 1

Question 4 continued

Leave
blank

Q4

(Total 12 marks)



5.

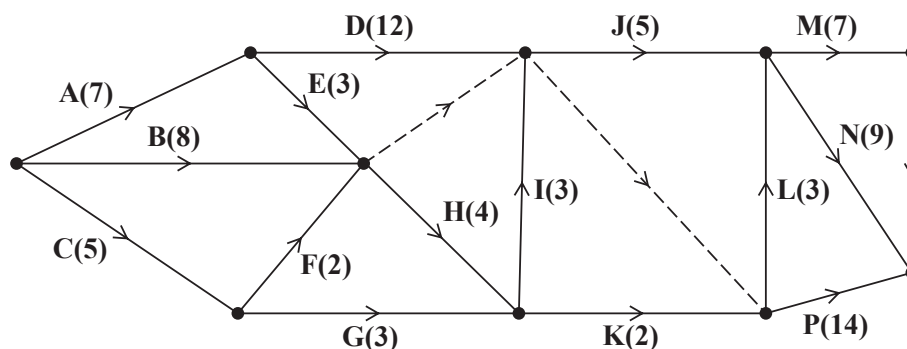


Figure 1

A project is modelled by the activity network shown in Figure 1. The activities are represented by the arcs. The number in brackets on each arc gives the time, in days, to complete the corresponding activity. Each activity requires exactly one worker. The project is to be completed in the shortest possible time.

- Complete Diagram 1 in the answer book to show the early event times and the late event times. (4)
- Calculate a lower bound for the number of workers needed to complete the project in the minimum time. You must show your working. (2)
- Schedule the activities on Grid 1 in the answer book using the minimum number of workers so that the project is completed in the minimum time. (4)

Additional resources become available, which can shorten the duration of one of activities D, G or P by one day.

- Determine which of these three activities should be shortened to allow the project to be completed in the minimum time. You must give reasons for your answer. (2)

(Total 12 marks)

5.

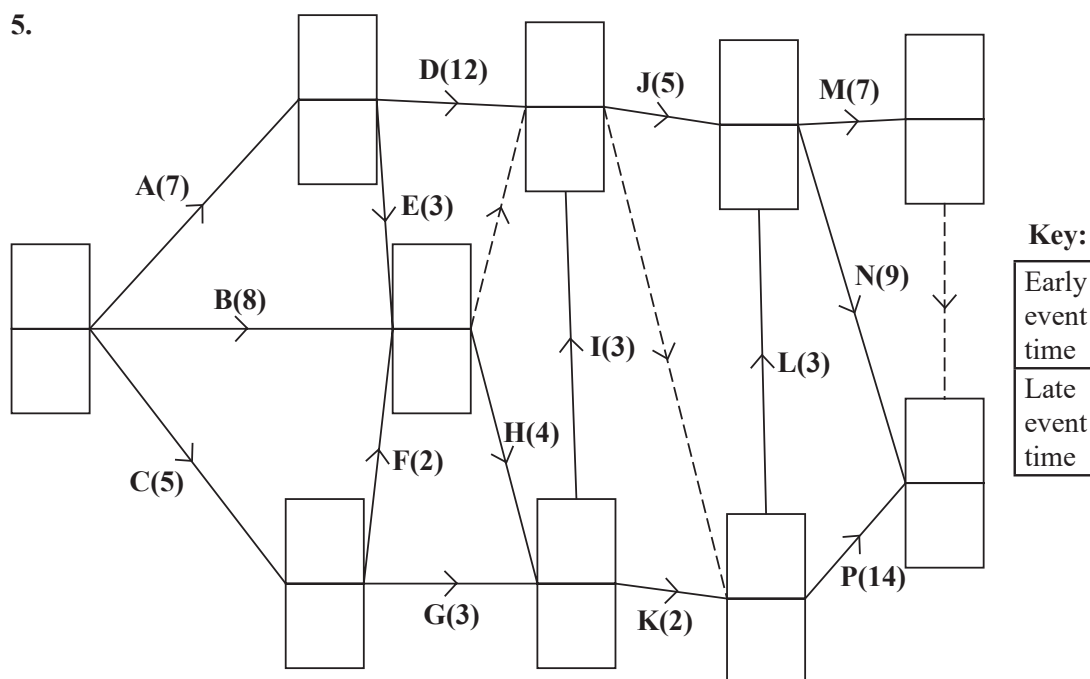


Diagram 1

Leave
blank

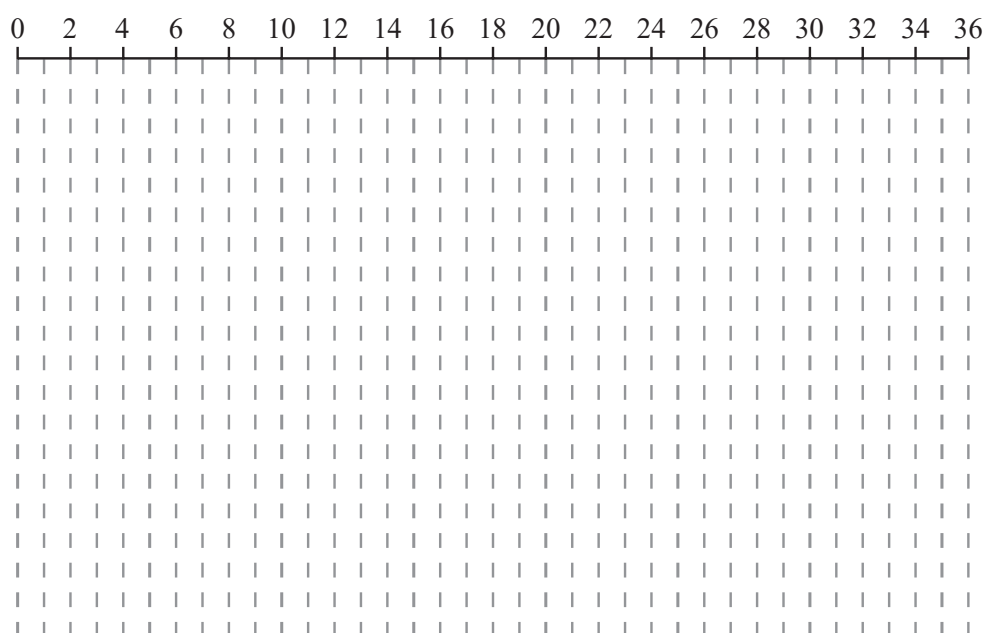
Key:

Early
event
time

Late event time	
-----------------------	--

Question 5 continued

Leave
blank



Grid 1

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

(Total 12 marks)

Q5



6.

Activity	Duration (days)	Immediately preceding activities
A	4	—
B	7	—
C	6	—
D	10	A
E	5	A
F	7	C
G	6	B, C, E
H	6	B, C, E
I	7	B, C, E
J	9	D, H
K	8	B, C, E
L	4	F, G, K
M	6	F, G, K
N	7	F, G
P	5	M, N

The table above shows the activities required for the completion of a building project. For each activity the table shows the duration, in days, and the immediately preceding activities. Each activity requires one worker. The project is to be completed in the shortest possible time.

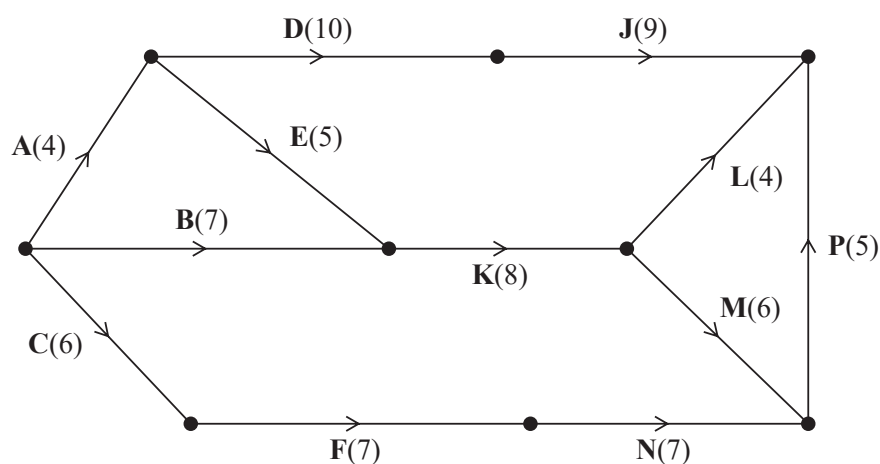


Figure 2

Figure 2 shows a **partially completed** activity network used to model the project. The activities are represented by the arcs and the numbers in brackets on the arcs are the times taken, in days, to complete each activity.

- (a) Complete the network in Diagram 1 in the answer book by adding activities G, H and I and the minimum number of dummies. (3)
- (b) Add the early event times and the late event times to Diagram 1 in the answer book. (4)
- (c) State the critical activities. (1)
- (d) Calculate a lower bound for the number of workers needed to complete the project in the shortest possible time. You must show your working. (2)
- (e) Schedule the activities on Grid 1 in the answer book, using the minimum number of workers, so that the project is completed in the minimum time. (3)

(Total 13 marks)

6. (a) and (b)

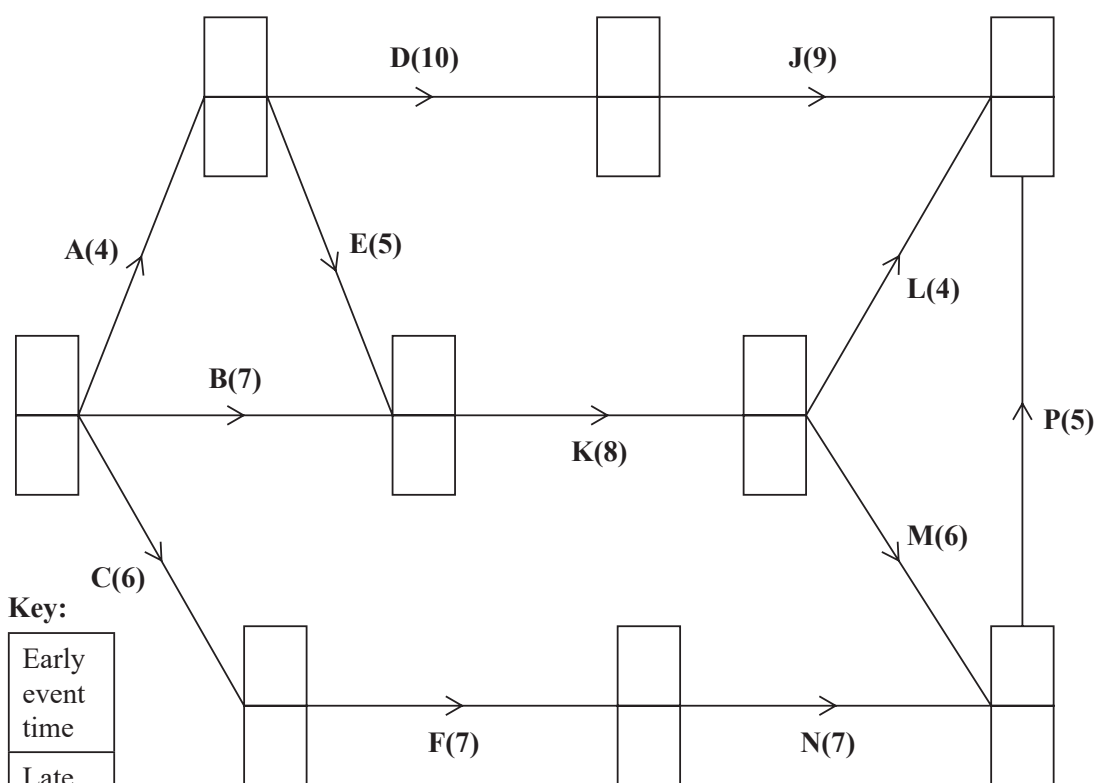
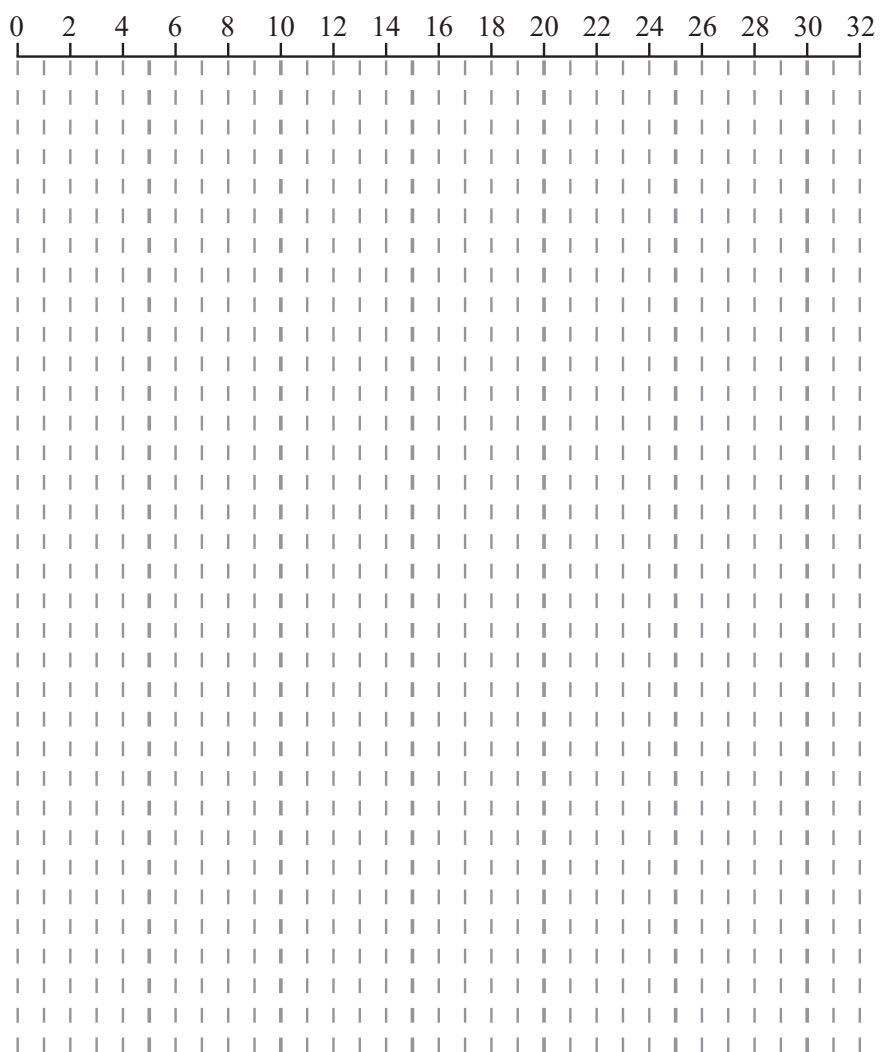


Diagram 1

Leave
blank

Question 6 continued

Leave
blank



Grid 1

(Total 13 marks)

Q6



4.

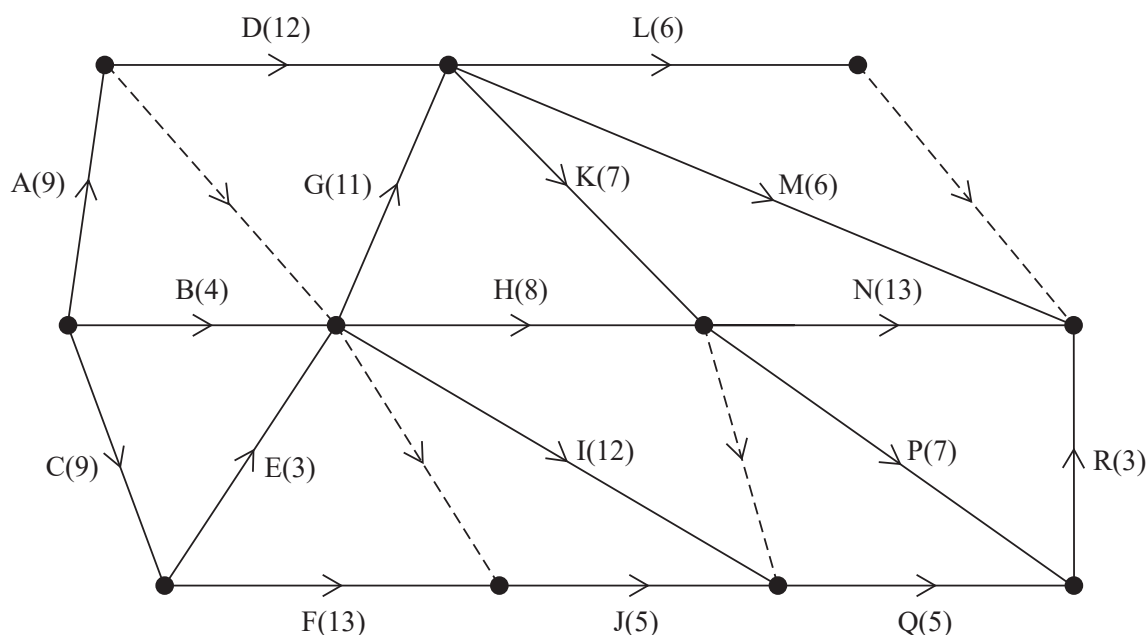


Figure 2

[The sum of the durations of all the activities is 133 days]

A project is modelled by the activity network shown in Figure 2. The activities are represented by the arcs. The number in brackets on each arc gives the time, in days, to complete the activity. Each activity requires one worker. The project is to be completed in the shortest possible time.

- Complete the precedence table in the answer book. (2)
 - Complete Diagram 1 in the answer book to show the early event times and the late event times. (4)
 - State the critical activities. (1)
 - Calculate the total float for activity J. You must make the numbers you use in your calculation clear. (1)
 - Calculate a lower bound for the number of workers needed to complete the project in the minimum time. You must show your working. (1)
- Diagram 2 in the answer book shows a partly completed scheduling diagram for this project.
- Complete the scheduling diagram, using the minimum number of workers, so that the project is completed in the minimum time. (4)

(Total for Question 4 is 13 marks)



4.

Activity	Immediately preceded by
A	–
B	–
C	–
D	A
E	C
F	C

Activity	Immediately preceded by
G	
H	
I	
J	
K	D, G
L	D, G

Activity	Immediately preceded by
M	D, G
N	
P	
Q	
R	

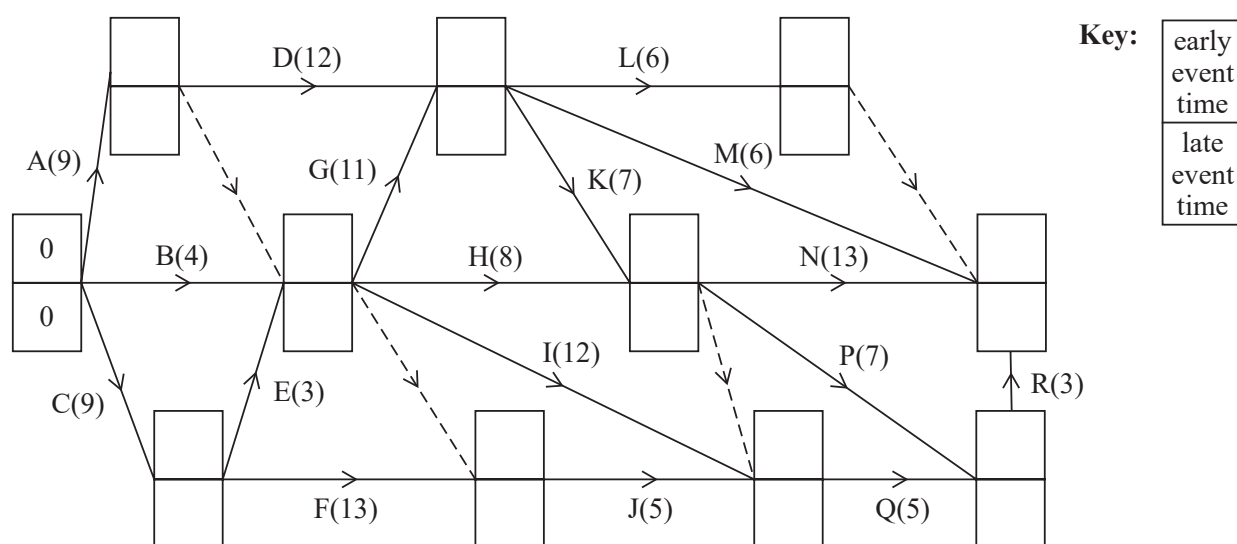


Diagram 1

Question 4 continued

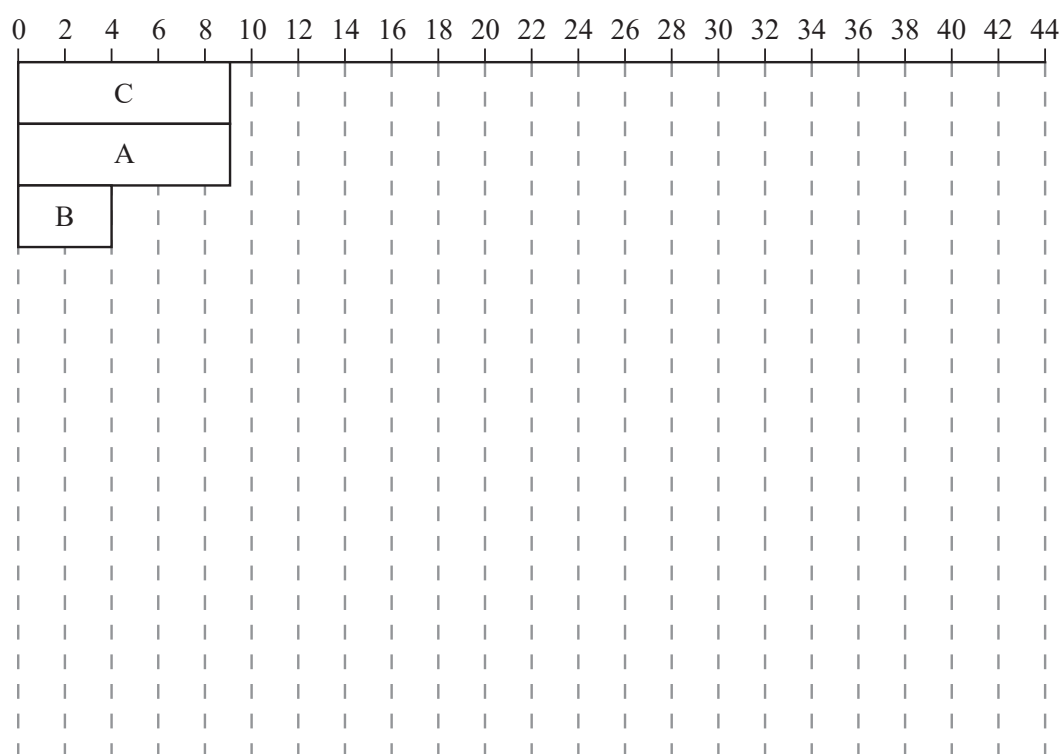


Diagram 2

(Total for Question 4 is 13 marks)

Write your answers in the D1 answer book for this paper.

1.

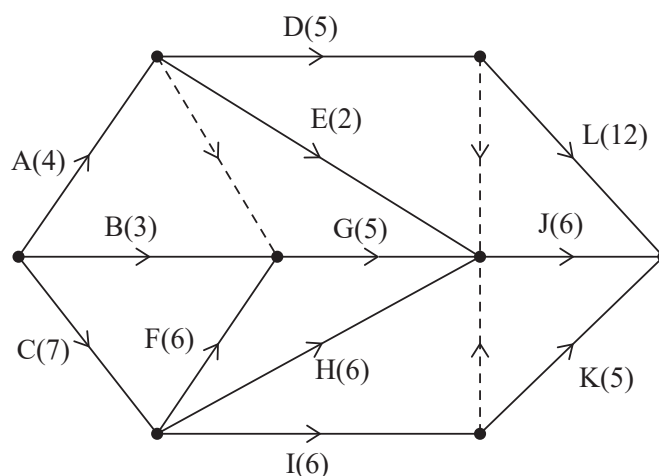


Figure 1

A project is modelled by the activity network shown in Figure 1. The activities are represented by the arcs. The number in brackets on each arc gives the time, in hours, to complete the corresponding activity. Each activity requires one worker. The project is to be completed in the shortest possible time using as few workers as possible.

- Complete Diagram 1 in the answer book to show the early event times and the late event times. (4)
- Calculate the total float for activity D. You must make the numbers used in your calculation clear. (1)
- Calculate a lower bound for the minimum number of workers required to complete the project in the shortest possible time. You must show your working. (2)
- Draw a cascade chart for this project on Grid 1 in the answer book. (4)
- Use your cascade chart to determine the minimum number of workers needed to complete the project in the shortest possible time. You must make specific reference to time and activities. (You do not need to provide a schedule of the activities.) (2)

(Total for Question 1 is 13 marks)

1.

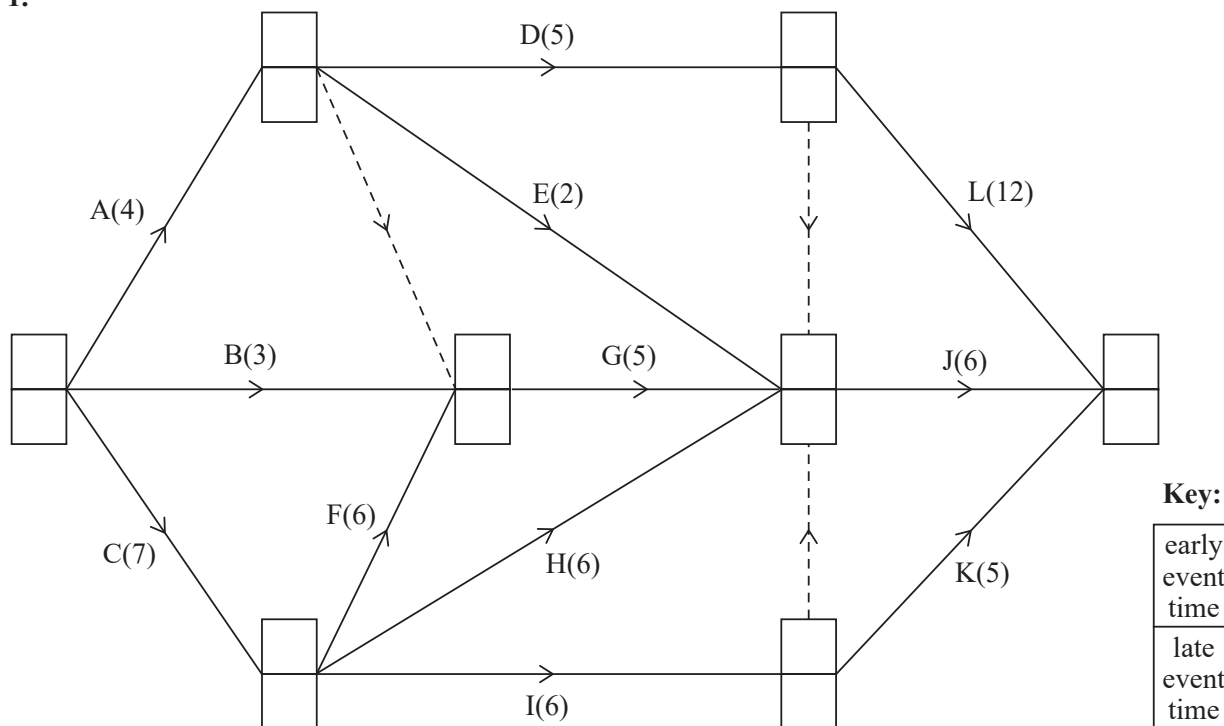
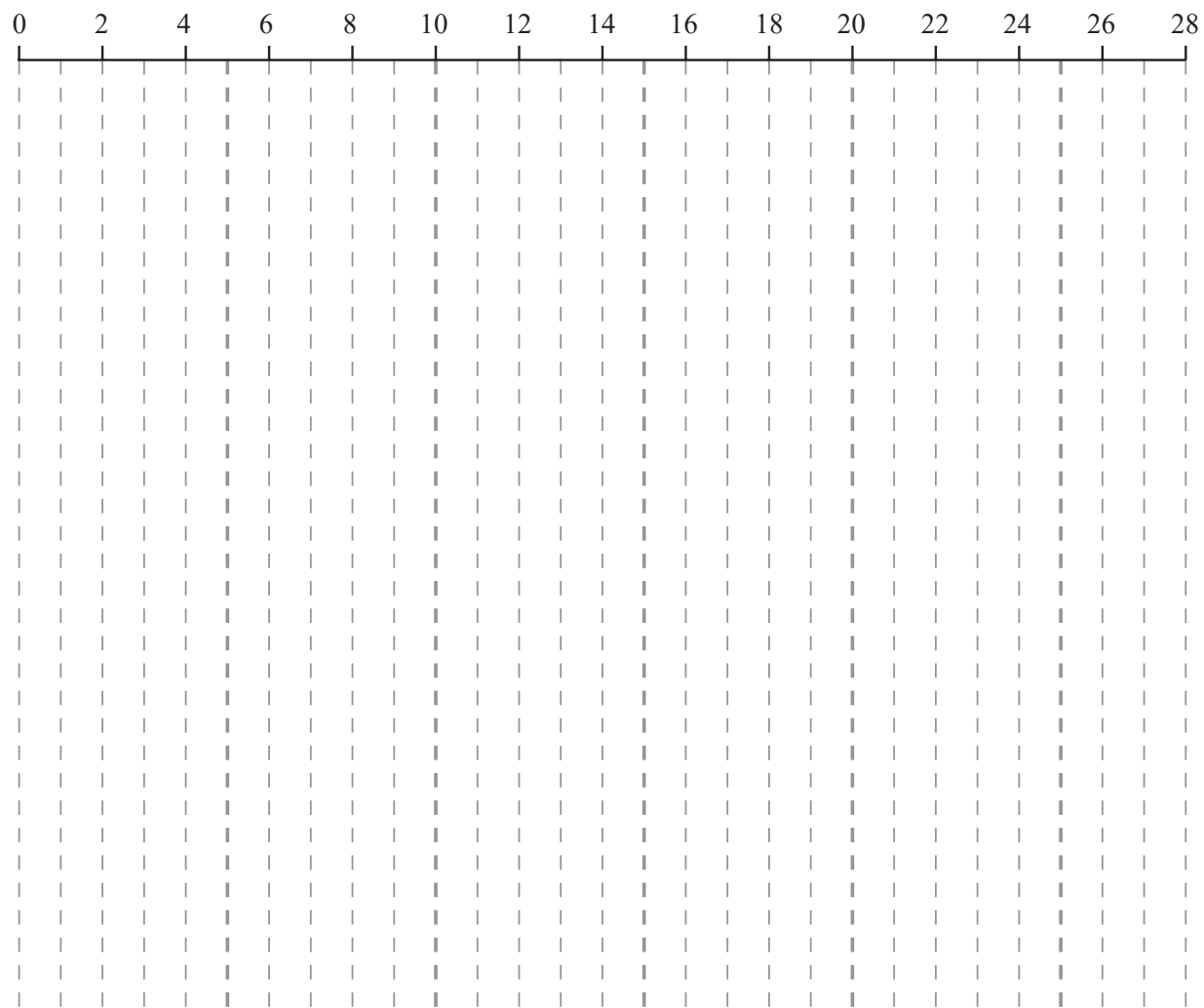


Diagram 1



Question 1 continued



Grid 1

(Total for Question 1 is 13 marks)

7.

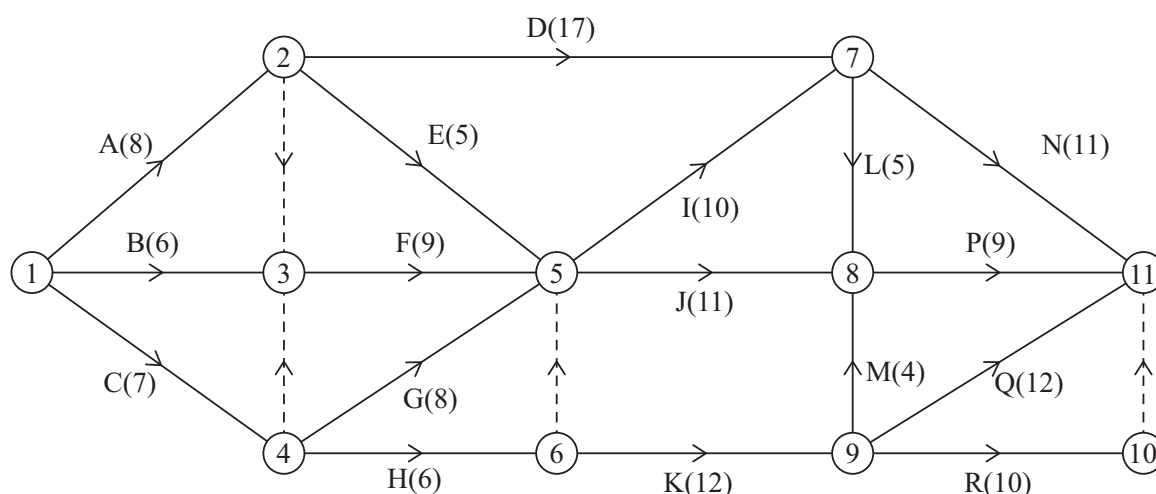


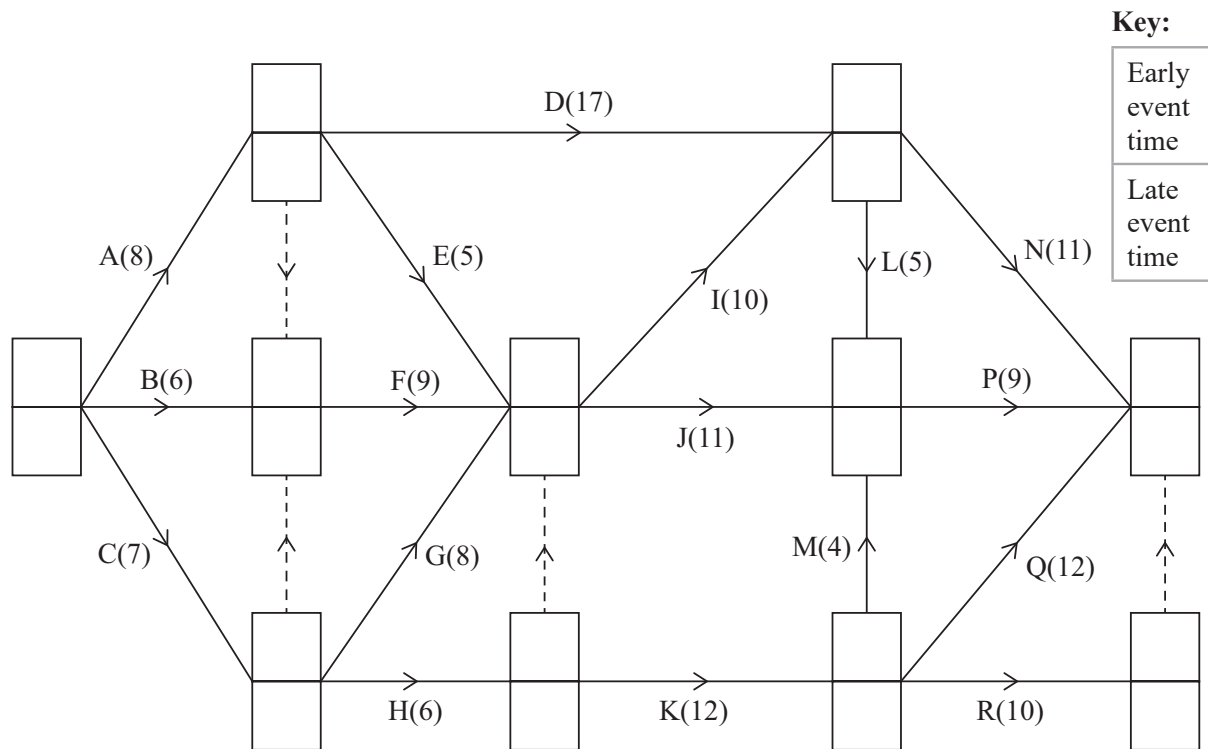
Figure 3

A project is modelled by the activity network shown in Figure 3. The activities are represented by the arcs. The number in brackets on each arc gives the time, in days, to complete the activity. Each activity requires exactly one worker. The project is to be completed in the shortest possible time.

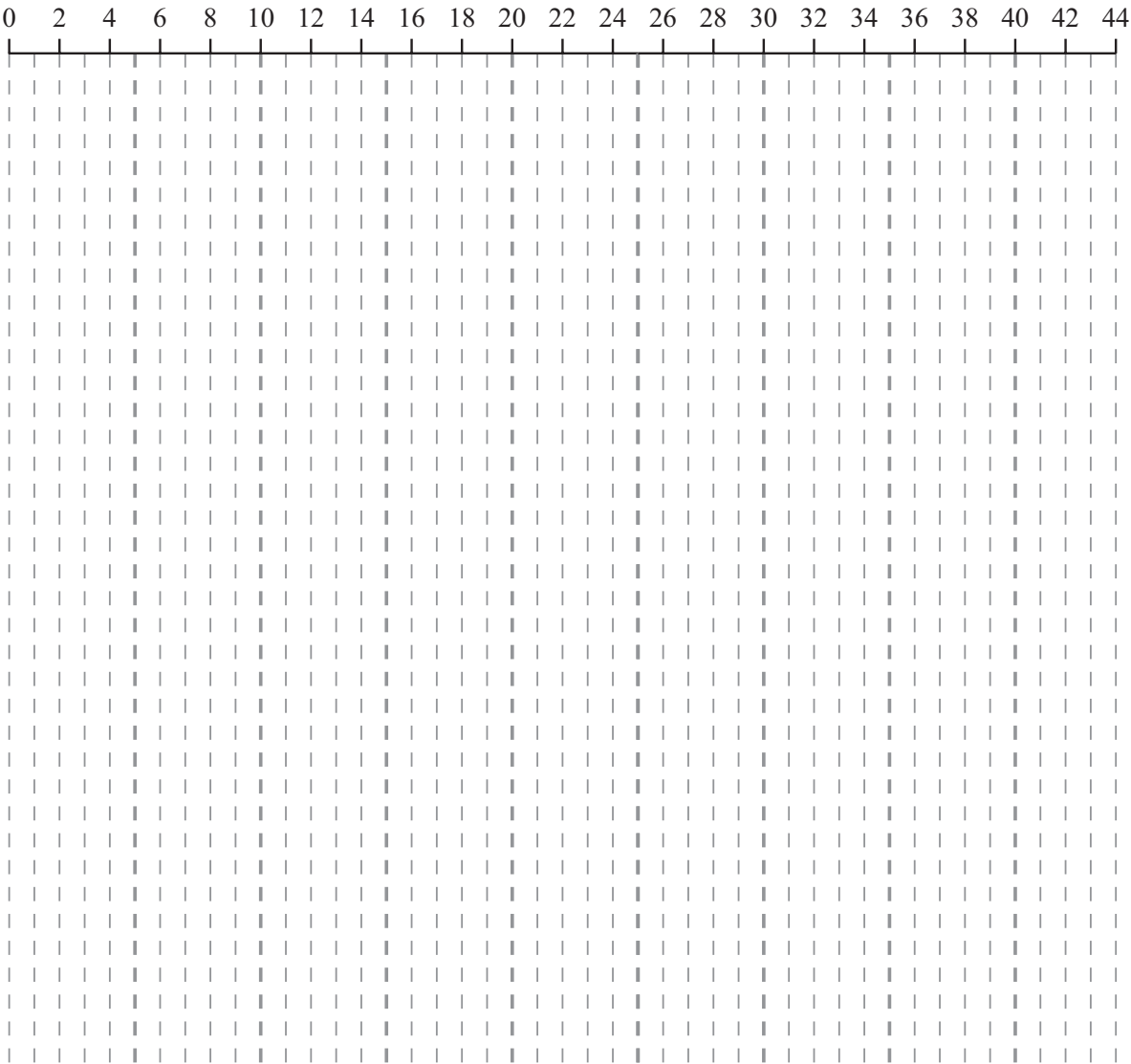
- Explain the purpose of the dummy between event 10 and event 11 (1)
- Complete Diagram 1 in the answer book to show the early event times and the late event times. (4)
- State the critical activities. (1)
- Calculate the maximum number of days by which activity K could be delayed without lengthening the completion time of the project. You must make the numbers used in your calculation clear. (2)
- Draw a Gantt (cascade) chart on the grid in the answer book. (4)
- Use the Gantt chart to determine a lower bound for the minimum number of workers required to complete the project in the minimum time. You must make specific reference to the number of workers, activities and times. (2)

(Total for Question 7 is 14 marks)

7.



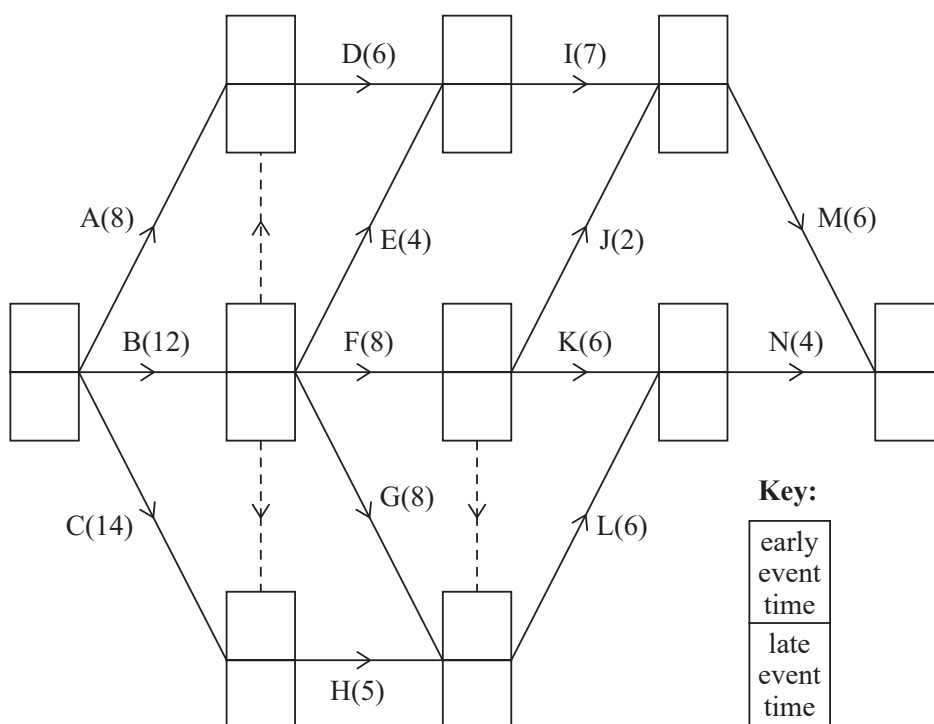
Question 7 continued



Handwritten area with horizontal lines for notes. The text "(Total for Question 7 is 14 marks)" is written at the bottom right of this section.

7.

Activity	Immediately preceding activities	Activity	Immediately preceding activities
A	—	H	
B	—	I	
C	—	J	
D		K	
E		L	
F		M	
G		N	

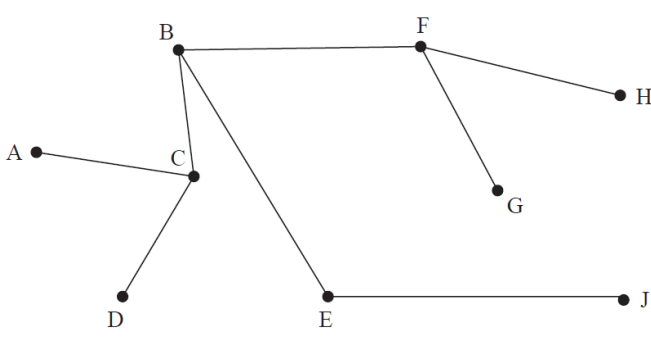
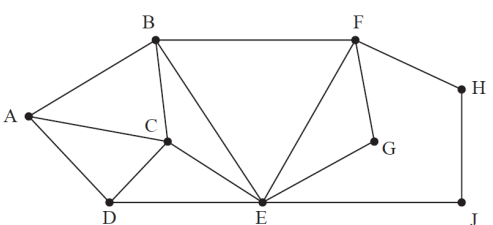




MARK SCHEMES

official mark schemes, in the same order as the questions



Question Number	Scheme	Marks
(c)	Kruskal: AC(9), BE(11), BF(12), not EF(14), FG(15), FH(17), not EG(18), EJ(20), $\left\{ \begin{array}{l} \text{not HJ (21)} \\ \text{BC (21)} \end{array} \right\}$, not CE(23), not AB(24), CD(25) (not DE, AD)	M1 A1 A1 (3)
(d)		B1 (1)
(e)	130 (km)	B1 (1)
		7 marks
Notes for Question 2		
a1B1: Any correct example of a path (so no vertex appearing more than once) from A to J b1B1: No with a correct reason i.e. must mention that a tour must begin and start at the same vertex, e.g. the route given does not finish at A scores B1 c1M1: Kruskal's algorithm - first four arcs (AC, BE, BF, FG) correctly chosen and at least one rejection seen at some point (the rejection need not be correct or at the correct time) c1A1: All arcs in tree selected correctly in the correct order (AC, BE, BF, FG, FH, EJ, BC, CD) with no additional arcs included in MST c2A1: cso - including all rejections correct and at the correct time (do not need to see DE and/or AD rejected but if they are rejected then must be after CD has been selected). Note that BC can be included before HJ rejected d1B1: cao e1B1: cao (130) – no units required/ignore units even if incorrect		
For reference:		
		
3.	e.g.	M1 A1

Question Number	Scheme	Marks																				
	Note that this solution is not unique e.g. A and B could be interchanged	A1 A1 A1 (5)																				
		5 marks																				
Notes for Question 3																						
Condone lack of, or incorrect, numbered events throughout. ‘Dealt with correctly’ means that the activity starts from the correct event but need not necessarily finish at the correct event, e.g. ‘D dealt with correctly’ requires the correct immediate precedences for this activity, i.e. A, B and C labelled correctly and leading into the same node and D starting from that node but do not consider the end event for D. Activity on node is M0 If one arc is not labelled, for example if the arc for activity F is not labelled (but the arc is present) then this will lose the first A mark and the final (CSO) A mark – they can still earn the second A mark on the bod. If two or more arcs are not labelled then mark strictly according to the scheme below and therefore no bod as mentioned above. Assume that a solid line is an activity which has not been labelled rather than a dummy (even if in the correct place for where a dummy should be) Ignore lack of arrows on the activities for the first four marks only a1M1: Seven activities (labelled on arc), one start and at least two dummies placed a1A1: Activities A, B, C, 1st two dummies (including correct arrows on these two dummies) and F dealt with correctly. The first two dummies are those at the end of activities A (or possibly B if A and B are interchanged in their network) and C a2A1: D, E, G and H dealt with correctly – this mark can be scored on the bod if the arrows are missing off the first two dummies provided the dummies are in the correct place a3A1: I and J dealt with correctly – so this requires the third and fourth dummies (including correct arrows) a4A1: cso – all arrows correctly placed for each activity with one finish and at most four dummies (so must have scored the first four marks) Please check all arcs carefully for arrows – if <u>no</u> dummy has an arrow then M1 only Note that additional (but unnecessary) ‘correct’ dummies that still maintain precedence for the network should only be penalised with the final A mark if earned For reference in checking immediately preceding activities (for ‘dealt with correctly’)																						
	<table><tr><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th><th>F</th><th>G</th><th>H</th><th>I</th><th>J</th></tr><tr><td>-</td><td>-</td><td>-</td><td>A, B, C</td><td>A, B, C</td><td>C</td><td>F</td><td>D</td><td>D, E, G</td><td>D, E</td></tr></table>	A	B	C	D	E	F	G	H	I	J	-	-	-	A, B, C	A, B, C	C	F	D	D, E, G	D, E	
A	B	C	D	E	F	G	H	I	J													
-	-	-	A, B, C	A, B, C	C	F	D	D, E, G	D, E													
4. (a)	Float on F is twice float on D $\Rightarrow 22 - 8 - y = 2(8 - 3 - x)$ (oe)	B1																				
	BFDM is 10 less than critical path	B1																				

Question Number	Scheme	Marks
4.(a)	e.g.	M1 A1 A1 A1 A1 (5)
(b)	Activities A, B, C, F and H are critical	B1 (1)
Notes for Question 4		
	Condone lack of, or incorrect, numbered events throughout. 'Dealt with correctly' means that the activity starts from the correct event but need not necessarily finish at the correct event, e.g. 'H dealt with correctly' requires the correct precedences for this activity, i.e. D and E labelled correctly and leading into the same node, a dummy from the end of F into the node and H starting from that node but do not consider the end event. Activity on node is M0	
	If an arc is not labelled, for example, if the arc for activity E is not labelled (but the arc is present) then this will lose the first A mark and the final (CSO) A mark – they can still earn the second A mark on the bod. If two or more arcs are not labelled then mark according to the scheme. Assume that a solid line is an activity which has not been labelled rather than a dummy (even if in the correct place for where a dummy should be). Ignore incorrect or lack of arrows on the activities for the first four marks only	
a1M1	Nine activities (labelled on arc), one start and at least two dummies placed	
a1A1	Activities A, B, C, 1 st two dummies (including correct arrow), D, E and F dealt with correctly	
a2A1	Activities G, H and I dealt with correctly and dummy from the end of F to end of D/E (including correct arrow)	
a3A1	Activities J and K dealt with correctly and dummy from the end of F to end of G (including correct arrow)	
a4A1	CSO – all arrows correctly placed for each activity with one finish and exactly five dummies (so uniqueness dummy for J/K required)	

	Please check all arcs carefully for arrows – if there are no arrows on any dummies then M1 only. Note that additional (but unnecessary) ‘correct’ dummies that still maintain precedence for the network should only be penalised with the final A mark if earned. Note that this answer is not unique (e.g. J and K are interchangeable, the arrow on the dummy between K and J can go in either direction or this dummy could be at the start of J and K)	
b1B1	CAO (A, B, C, F and H and no others, but condone mention of D and/or I)	

Question Number	Scheme	Marks
5. (a)		M1 A1 A1 A1 A1 (5)
(b)	Activities E, I, J and L cannot be critical	M1 A1 (2)
		7 marks

Notes for Question 5

Condone lack of, or incorrect, numbered events throughout. 'Dealt with correctly' means that the activity starts from the correct event but need not necessarily finishes at the correct event, e.g. 'F dealt with correctly' requires the correct precedences for this activity, i.e. A, B and C labelled correctly and leading into the same node and F starting from that node but do not consider the end event for F. The table below is very useful in checking this point. **Activity on node is M0**

If an arc is not labelled, for example, if the arc for activity E is not labelled (but the arc is present) then this will lose the first A mark and the final (CSO) A mark – they can still earn the second A mark on the bod. If two or more arcs are not labelled then mark according to the scheme. Assume that a solid line is an activity which has not been labelled rather than a dummy (even if in the correct place for where a dummy should be) '

Ignore incorrect or lack of arrows on the activities for the first four marks only

a1M1: Seven activities (labelled on arc), one start and at least two dummies placed

a1A1: Activities A, B, C, 1st two dummies (including correct arrows on these two dummies), D and E dealt with correctly. The first two dummies are those at the end of activities A and C

a2A1: A dummy linking D, F and G into an event node and a dummy linking D, F, G, I and E into an event node and F, G and I dealt with correctly. The dummies must have arrows

a3A1: Activities H, J, K and L dealt with correctly

a4A1: CSO – all arrows correctly placed for each activity with one finish and at most four dummies. Note that this is not a unique solution due to for example the 3rd and 4th dummies so please check these carefully.

Please check all arcs carefully for arrows – if there are no arrows on any dummies then M1 only.

Note that additional (but unnecessary) 'correct' dummies that still maintain precedence for the network should only be penalised with the final A mark if earned

b1M1: At least two correct activities with no more than 5 activities stated

b1A1: All four activities (E, I, J and L) and no others

A	B	C	D	E	F	G	H	I	J	K	L
-	-	-	A	C	A, B, C	A, B, C	D, F, G	A, B, C	D, F, G	H	D, E, F, G, I



Question Number	Scheme	Marks
6. (a)	Shortest time: 45 (minutes) Quickest route: A C B D F G J	M1 A1 (CEBD) A1 (FH) A1ft (GJ) A1ft A1 (6)
(b)	$A(CB)D + HJ = 20 + 20 = 40$ $A(CBDF)H + D(FG)J = 26 + 25 = 51$ $A(CBDFG)J + D(F)H = 45 + 6 = 51$ Repeated arcs: AC, BC, BD, HJ	M1 A1 A1 A1 A1 (5)
(c)(i)	Vertex C: 4 times	B1
(ii)	Vertex D: 3 times	B1
(d)	H to H requires the consideration of the shortest path from A to J only (as these are the only two odd nodes) $314 > 309$ or $45 > 40$ so quicker to start at H and finish at D	B1 B1 (2)
		15 marks

Notes for Question 6

In (a) it is important that all values at each node are checked very carefully – the order of the working values must be correct for the corresponding A mark to be awarded e.g. at J the working values must be 49 46 45 in that order (so 49 45 46 is incorrect)

It is also important that the order of labelling is checked carefully. The order of labelling must be a strictly increasing sequence – so 1, 2, 3, 3, 4, ... will be penalised once (see notes below) but 1, 2, 3, 5, 6, ... is fine. Errors in the final values and working values are penalised before errors in the order of labelling

a1M1: A larger value replaced by a smaller value in at least two of the working value boxes at any node except A or C

a1A1: All values at C, E, B and D correct and the working values in the correct order (including order of labelling)

a2A1: All values at F and H correct and the working values in the correct order. Penalise order of labelling only once per question (F and H must be labelled in that order and F must be labelled after C, E, B and D)

a3A1ft: All values in G and J correct on the follow through and the working values in the correct order. Penalise order of labelling only once per question. To follow through G check that the working value at G follows from the candidate's final values from their feeds into G (which will mostly likely come from nodes B, D and F (in the order in which the candidate has labelled them)) and that the final value, and order of labelling, follows through correctly. Repeat this process for J (which will possibly have working values from E, H and G with the order of these values determined by the candidate's order of labelling at E, H and G)

Question Number	Scheme	Marks
4.(a)		M1 A1 A1 A1 A1 (5)
(b)	D and F are guaranteed to be critical	B1 (1)
(c)	Critical path: A – C – G – I – J	B1 (1)
		7 marks

Notes for Question 4

In (a) condone lack of, or incorrect, numbered events throughout – also ‘dealt with correctly’ means that the activity starts from the correct event but may not finish at the correct event (use the table below to check this). **Activity on node is M0**

If an arc is not labelled, for example, if the arc for activity D is not labelled (but the arc is present) then this will lose the first A mark and the final (CSO) A mark – they can still earn the second A mark on the bod. If two or more arcs are not labelled then mark according to the scheme. Assume that a solid line is an activity which has not been labelled rather than a dummy (even if in the correct place for where a dummy should be)

Ignore incorrect or lack of arrows on the activities for the first four marks only

a1M1: Eight activities (labelled on arc), one start and at least two dummies placed

a1A1: Activities A, B, C, 1st dummy (+ correct arrow on this dummy – this is the dummy at the end of A) and D dealt with correctly

a2A1: 2nd and 3rd dummies (+ correct arrows on these dummies – these dummies are the ones at the end of C and D) and E, F and G dealt with correctly

a3A1: 4th dummy (+ correct arrow on this dummy – this is the dummy at the end of F) and activities H, I, J and K dealt with correctly

a4A1: CSO – all arrows present and correctly placed with one finish

Please check all arcs carefully for arrows – if there are no arrows on any dummies then M1 only.

Note that additional (but unnecessary) ‘correct’ dummies that still maintain precedence for the network should only be penalised with the final A mark if earned

b1B1: CAO (D and F) and no other activities stated as critical (however, ignore K if stated too)

c1B1: CAO (A – C – G – I – J)

Activity	A	B	C	D	E	F	G	H	I	J	K
IPA	-	-	A	A, B	C, D	D	C	G	G	E, F, I	F

Question Number	Scheme	Marks
5.(a)		M1 A1 M1 A1 (4)
(b)	Lower bound is $\frac{87}{33} = 2.6363... = 3$	M1 A1 (2)
(c)	e.g. 	M1 A1 A1 A1 (4)
(d)	G is not a critical activity (it has a total float of $16 - 5 - 3 = 8$ days) and so there is no benefit from reducing the duration of G by one day Activities D and P are both critical activities	M1
	However, D appears in both critical paths therefore reducing P would not reduce the minimum completion time (as there is still a critical path A – D – J – N of length 33) and so activity D should be shortened by one day	A1 (2)
		12 marks
Notes for Question 5		
a1M1: All top boxes complete, values generally increasing in the direction of the arrows ('left to right'), condone one rogue a1A1: CAO (top boxes) a2M1: All bottom boxes complete, values generally decreasing in the opposite direction of the arrows ('right to left'), condone one rogue. Condone missing 0 and/or their 33 (at the end event) for the M mark only a2A1: CAO (bottom boxes) b1M1: Attempt to find lower bound: (a value in the interval $[73 - 101]$ / their finish time) or (sum of the activities / their finish time) or (as a minimum) an awrt 2.6 b1A1: CSO – requires both a correct calculation or awrt 2.6 seen and 3. An answer of 3 with no working scores no marks c1M1: Not a cascade chart. 4 workers used at most, at least 10 activities placed c1A1: 3 workers. All 15 activities present (just once). Condone two errors. An activity can give rise to at most three errors; one on duration, one on time interval and only one on IPA c2A1: 3 workers. All 15 activities present (just once). Condone one error. An activity can give rise to at most three errors; one on duration, one on time interval and only one on IPA		

Question Number	Scheme	Marks
4.(a)	$y \leq 2x$ and $3x + y \leq 30$	B1
	Correct method for finding the third boundary of the feasible region	M1
	$5y \geq 6x + 10$	A1 (3)
(b)	(6, 12)	B1
	Solving simultaneous equations to find the other two vertices	M1
	$\left(\frac{5}{2}, 5\right)$ and $\left(\frac{20}{3}, 10\right)$	A1 (3)
(c)	$\left(\frac{5}{2}, 5\right) \rightarrow P = 20$ $\left(\frac{20}{3}, 10\right) \rightarrow P = \frac{130}{3}$ $(6, 12) \rightarrow P = 48$	M1 A1
	Optimal vertex is (6,12) with $P = 48$	A1 (3)
(d)	$12 + 12k \square 2\left(\frac{20}{3}\right) + 10k$ where $\square$ is any inequality or equals	M1
	$k \geq \frac{2}{3}$	A1 (2)
		11 marks

Notes for Question 4

a1B1: Both correct inequalities: $y \leq 2x$ and $3x + y \leq 30$ (or equivalent if they have been rearranged)

a1M1: Correct equation for the third boundary of the feasible region, e.g. $\frac{y-20}{14-20} = \frac{x-15}{10-15}$ would score

M1 (so does not need to be simplified). Condone any inequality sign used (provided that if the inequality sign was replaced with an 'equals' then the equation ($5y = 6x + 10$) would be correct). ISW once the correct equation has been seen (so condone the correct unsimplified equation if not simplified correctly)

a1A1: CAO for third inequality – must be three terms only but need not be further simplified (e.g. $12x - 10y + 20 \leq 0$, $y \geq 1.2x + 2$ etc. scores **A1**)

b1B1: (6, 12) or $x = 6$, $y = 12$

b1M1: Correct method for solving their simultaneous equations (so $y = 2x$ with their $5y = 6x + 10$ or $3x + y = 30$ with their $5y = 6x + 10$) to find both the x and y -coordinates of at least one of the other two vertices (can be implied by either vertex stated correctly – condone non-exact values (to at least 3 sf) for this mark if no working seen)

b1A1: CAO $(2.5, 5)$ and $\left(\frac{20}{3}, 10\right)$ (must be exact, so accept $(6\frac{2}{3}, 10)$, $(6.\dot{6}, 10)$, etc. but not $(6.6666\dots, 10)$)

c1M1: Testing their three **vertices** (not just points in the FR) in the correct objective function ($P = 2x + 3y$). Condone one slip only when applying the objective function to one of their three vertices (so they must apply the correct objective to at least two of their three points but condone a single slip in the third)

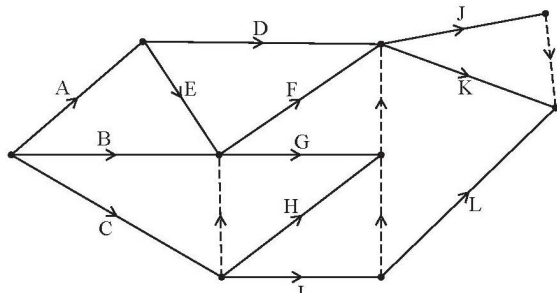
c1A1: At least two correct (therefore exact) points tested correctly (so at least two correct values of P explicitly stated – allow awrt 43.3 when testing $(20/3, 10)$)

c2A1: CSO all three correct (therefore exact) points tested correctly (so all three correct values of P explicitly seen – allow awrt 43.3 when testing $(20/3, 10)$) with a clear indication of which is the optimal vertex (this can be achieved by either making it clear that (6, 12) is the optimal point or that $P = 48$ is the maximum (as one implies the other))

d1M1: (6, 12) **and** their $\left(\frac{20}{3}, 10\right)$ (does not need to be exact) correctly substituted into $P = 2x + ky$ and compared (by comparing we mean forming an equation or any inequality). **Or** comparing $-\frac{2}{k}$ with -3 (so using the gradient of the objective line) **or** comparing $\frac{2}{k}$ with 3 **or** their reciprocals (e.g. $\frac{k}{2}$ compared with $\frac{1}{3}$ etc.) but comparing $-\frac{2}{k}$ with 3 is **M0** (by comparing we mean forming an equation or any inequality with the **correct** pairs of values)

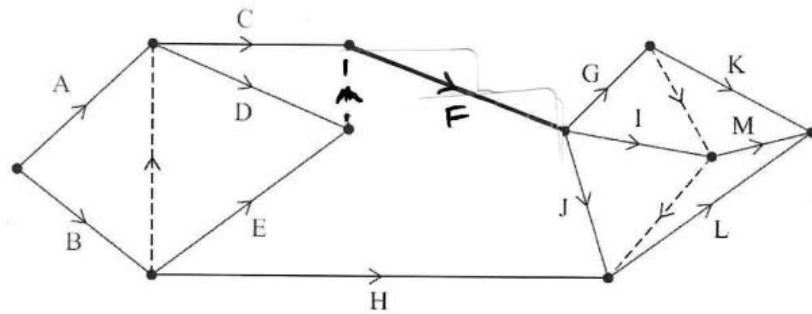
d1A1: CAO either $k \geq \frac{2}{3}$ or $k > \frac{2}{3}$ **only** (or exact equivalents) – if any other answers given with $k \geq \frac{2}{3}$ e.g. $k \geq -1$ then **A0** (unless clearly rejected). Correct answer with no working can score both marks in this part. Please ensure that if working is shown that the correct answer of $k \geq \frac{2}{3}$ comes from correct working e.g.

$$-\frac{2}{k} \geq -3$$

Question Number	Scheme	Marks																										
5. (a)	e.g. 	M1																										
		A1																										
		A1																										
		A1																										
		A1																										
		(5)																										
(b)	Duration of activity K is $33 - 10 - 7 - 8 = 8$ or the path AEFJ has a duration of < 33	M1																										
	Therefore the duration of J is less than 8 hours or $0 < \text{dur}(J) < 8$	A1																										
		(2)																										
		7 marks																										
Notes for Question 5																												
Condone lack of, or incorrect, numbered events throughout. ‘Dealt with correctly’ means that the activity starts from the correct event but need not necessarily finish at the correct event and appears only once in the network , e.g. ‘G dealt with correctly’ requires the correct precedences for this activity, i.e. B, C and E labelled correctly and leading into the same node and G starting from that node but do not consider the end event for G so use the table below for checking as there a number of acceptable answers. Activity on node is M0																												
If an arc is not labelled, for example, if the arc for activity E is not labelled (but the arc is present) then this will lose the first A mark and the final (CSO) A mark – they can still earn the second A mark on the bod. If two or more arcs are not labelled then mark according to the scheme. Assume that a solid line is an activity which has not been labelled rather than a dummy (even if in the correct place for where a dummy should be)																												
Ignore incorrect or lack of arrows on the activities for the first four marks only (but assume that they are in the ‘correct’ direction for checking purposes)																												
a1M1: At least seven activities (labelled on arc), one start and at least two dummies placed a1A1: Activities A, B, C, D and E dealt with correctly a2A1: Activities F, G, H and I dealt with correctly (so a dummy is required at the end of C + correct arrow) a3A1: Activities J, K and L dealt with correctly (so at least two further dummies required + correct arrows) a4A1: CSO – all arrows correctly placed for each activity with one finish and at most four dummies. Please check all arcs carefully for arrows – if there are no arrows on any dummies then M1 only. Note that additional (but unnecessary) ‘correct’ dummies that still maintain precedence for the network should only be penalised with the final A mark if earned																												
Extremely useful for checking (a)																												
<table><tr><th>Activity</th><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th><th>F</th><th>G</th><th>H</th><th>I</th><th>J</th><th>K</th><th>L</th></tr><tr><td>IPA</td><td>-</td><td>-</td><td>-</td><td>A</td><td>A</td><td>B, C, E</td><td>B, C, E</td><td>C</td><td>C</td><td>D, F, G, H, I</td><td>D, F, G, H, I</td><td>I</td></tr></table>			Activity	A	B	C	D	E	F	G	H	I	J	K	L	IPA	-	-	-	A	A	B, C, E	B, C, E	C	C	D, F, G, H, I	D, F, G, H, I	I
Activity	A	B	C	D	E	F	G	H	I	J	K	L																
IPA	-	-	-	A	A	B, C, E	B, C, E	C	C	D, F, G, H, I	D, F, G, H, I	I																
b1M1: Either the correct method for calculating the duration of activity K seen (e.g. $33 - 10 - 7 - 8$ or an answer of 8 can imply this mark) or stating the path AEFJ will have a duration < 33 or ≤ 33 b1A1: Correct indication that the duration of K being 8 implies that J’s duration is < 8 (allow ≤ 8 but A0 for ≤ 7). As a minimum for both marks candidates must either say that the duration of K is 8 (e.g. $K = 8$) or that the path AEFJ has a duration < 33 or ≤ 33 , together with the duration of J being either < 8 or ≤ 8 . A lower limit is not required but if stated then it must be either > 0 or ≥ 0 only																												

Question Number	Scheme	Marks
6.(a)(i)	Shortest path from A to J: ADCFEHGJ	M1 A1 (ABDC) A1 (FE) A1ft (HGJ) A1
(a)(ii)	Length of shortest path from A to J: 67 (miles)	A1ft (6)
(b)	$AC + EJ = A(D)C + E(HG)J = 21 + 31 = 52$ $AE + CJ = A(DCF)E + C(FE)HGJ = 36 + 46 = 82$ $AJ + CE = A(DCFE)HGJ + C(F)E = 67 + 15 = 82$ Route length is $315 + 52 = 367$ (miles)	M1 A1 A1 A1ft (4)
(c)	Pass through G a total of 3 times	B1 (1)
(d)	Difference in inspection routes is $67 - 52 = 15$ (miles)	B1ft (1)
(e)	Arcs CF and EF do not need to be repeated	B1 (1)
		13 marks
	Notes for Question 6	
	In (a) it is important that all values at each node are checked very carefully – the order of the working values must be correct for the corresponding A mark to be awarded e.g. at F the working values must be 40 35 31 in that order (so 40 31 35 is incorrect) It is also important that the order of labelling is checked carefully. The order of labelling must be a strictly increasing sequence – so 1, 2, 3, 3, 4, ... will be penalised once (see notes below) but 1, 2, 3, 5, 6, ... is fine. Errors in the final values and working values are penalised before errors in the order of labelling	

4.(a)		M1 A1 A1 A1 A1 (5)
	oe (see below)	
(b)(i)	Activities A, C, D and H cannot be critical	B1
(b)(ii)	Activities B and F must be critical	B1 (2)
		7 marks
	Notes for Question 4	
	Condone lack of, or incorrect, numbered events throughout. ‘Dealt with correctly’ means that the activity starts from the correct event but need not necessarily finish at the correct event, e.g. ‘L dealt with correctly’ requires the correct precedences for this activity, i.e. H and J labelled correctly and leading into the same node and L starting from that node but do not consider the end event for L. Activity on node is M0	
	If an arc is not labelled, for example, if the arc for activity E is not labelled (but the arc is present) then this will lose the first A mark and the final (CSO) A mark – they can still earn the second A mark on the bod. If two or more arcs are not labelled then mark according to the scheme. Assume that a solid line is an activity which has not been labelled rather than a dummy (even if in the correct place for where a dummy should be). Ignore incorrect or lack of arrows on the activities for the first four marks only	
a1M1	Nine activities (labelled on arc), one start and at least two dummies placed	
a1A1	Activities A, B, 1 st dummy (including correct arrow), C, D, E and H dealt with correctly	
a2A1	2 nd dummy (including correct arrow), activities F, G, I and J dealt with correctly	
a3A1	Activities K, L and M dealt with correctly (so third and fourth dummies required + arrows)	
4A1	CSO – all arrows correctly placed for each activity with one finish and at most four dummies.	
	Please check all arcs carefully for arrows – if there are no arrows on any dummies then M1 only. Note that additional (but unnecessary) ‘correct’ dummies that still maintain precedence for the network should only be penalised with the final A mark if earned	
b1B1	CAO (A, C, D and H and no others)	
b2B1	CAO (B and F and no others – accept though if E mentioned)	



Alternative equivalent graph

Activities C and D may be interchanged on either version

Question Number	Scheme	Marks
6.(a)		M1 A1 A1 A1 A1 (5)
(b)	Critical path: A – E – K	B1 (1)
(c)	First critical path: C – H – I – M Second critical path: C – H – I – L	B1 B1 (2)
		8 marks

Notes for Question 6

Condone lack of, or incorrect, numbered events throughout. ‘Dealt with correctly’ means that the activity starts from the correct event but need not necessarily finish at the correct event, e.g. ‘F dealt with correctly’ requires the correct precedences for this activity, i.e. A, B and C labelled correctly and leading into the same node and F starting from that node but do not consider the end event for F. **Activity on node is M0**

If an arc is not labelled, for example, if the arc for activity G is not labelled (but the arc is present) then this will lose the second A mark and the final (CSO) A mark – they can still earn the third A mark on the bod. If two or more arcs are not labelled then mark according to the scheme. Assume that a solid line is an activity which has not been labelled rather than a dummy (even if in the correct place for where a dummy should be)

Ignore incorrect or lack of arrows on the activities for the first four marks only

a1M1: At least eight activities (labelled on arc), one start and at least two dummies placed

a1A1: Activities A, B, C, first two dummies (+ correct arrows on these two dummies) and D dealt with correctly – the first two dummies are those that meet at the end of activity B

a2A1: Activities E, F, G, H and I dealt with correctly

a3A1: Activities J, K, L and M and 3rd dummy (+ correct arrow on this dummy) dealt with correctly – the 3rd dummy is the one that begins at the end of activity G

a4A1: CSO – Final dummy + arrow, all arrows correctly placed for each activity with one finish and no additional dummies. Note that this is not a unique solution e.g. J and K could be interchanged, or the dummy could come immediately after E, etc. so please check these carefully. **Please check all arcs carefully for arrows – if there are no arrows on dummies then M1 only.**

Note that additional (but unnecessary) ‘correct’ dummies that still maintain precedence for the network should only be penalised with the final A mark if earned

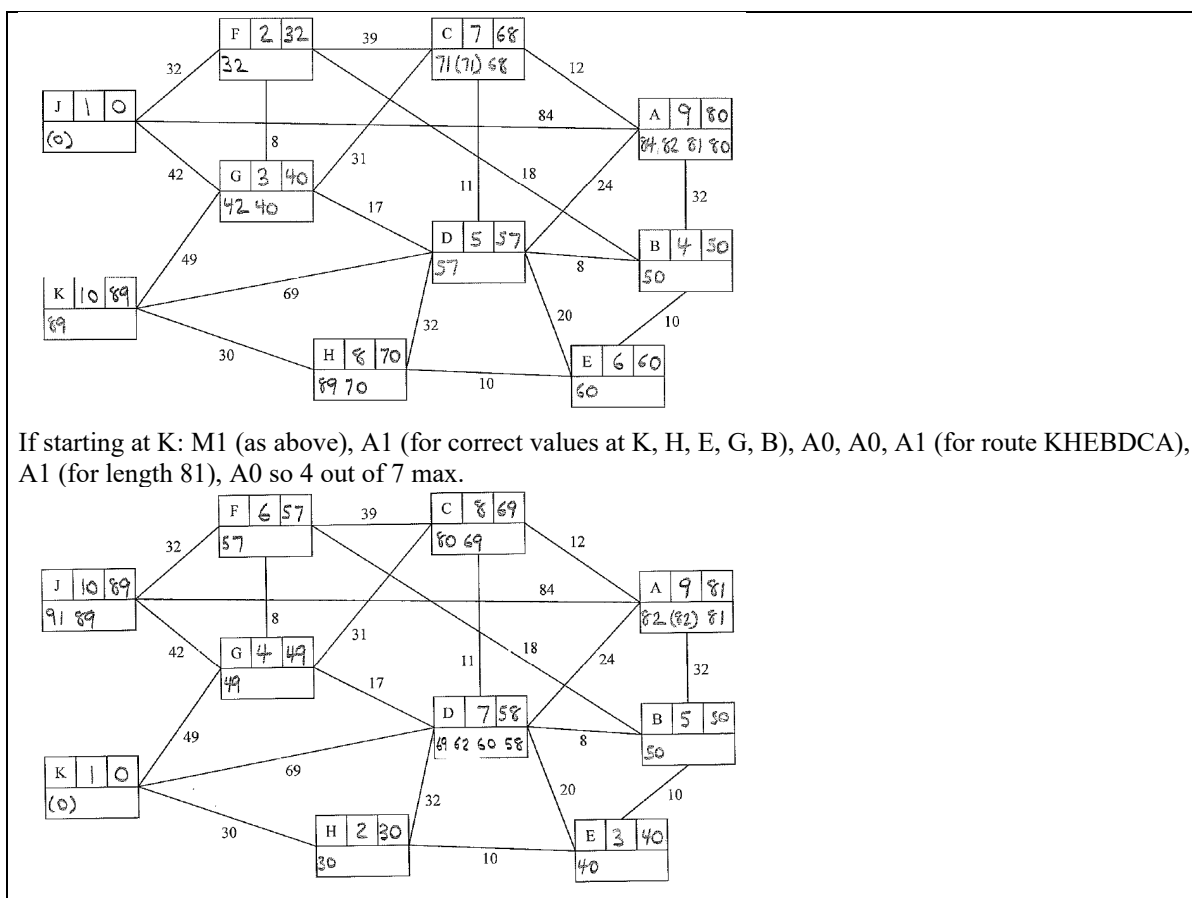
b1B1: CAO (A, E and K only)

c1B1: One correct path (with at most three paths stated)

c2B1: Both correct with no others

Question Number	Scheme	Marks
3.(a)	$x = 8, y = 12, z = 17$	B3, 2, 1, 0 (3)
(b)		M1 A1 A1 A1 (4)
(c)	Lower bound is 4 workers e.g. activities J, K, L and M together with $24 < \text{time} < 26$	M1 A1 (2)
		9 marks

Notes for Question 3**a1B1:** x value correct**a2B1:** y value correct**a3B1:** z value correct**b1M1:** At least ten activities labelled including at least five floats. A scheduling diagram scores M0**b1A1:** The critical activities dealt with correctly and appearing just once (C, H, I and J) and three non-critical activities dealt with correctly**b2A1:** Any six non-critical activities correct (this mark is not dependent on the previous A mark)**b3A1:** CSO – completely correct Gantt chart (exactly thirteen activities appearing just once)**c1M1:** Either a statement with the correct number of workers (4) and the correct activities (J, K, L and M) with any numerical time stated **or** the correct number of workers (4) and a time in the interval $24 \leq x \leq 26$ – mark the numerical value only not their use of day/time**c1A1:** A completely correct statement with details of both time and activities. Candidates must give a time within the correct interval of $24 < t < 26$. Please note the strict inequalities for the time interval (e.g. implying a time of 24 is incorrect). Answers given as an interval of time are acceptable provided the time interval stated is correct for all its possible values (e.g. time 25 – 26 is A0). Note that ‘on day 25’ or ‘on day 26’ are correct but ‘on day 24’ is not correct. A completely correct statement with an additional incorrect statement scores A0 (so no isw)



If starting at K: M1 (as above), A1 (for correct values at K, H, E, G, B), A0, A0, A1 (for route KHEBDCA), A1 (for length 81), A0 so 4 out of 7 max.

Question Number	Scheme	Marks
6.(a)	c.g.	M1 A1 A1 A1 A1 (5)

(b)	Activity I is guaranteed to be critical...	M1
	...because all paths (from source to sink) contain activity I	A1 (2)
(c)	Minimum project completion time is 12 (hours)	B1
	Critical path is C G H I L M	B1 (2)
		9 marks

Notes for Question 6

In (a) condone lack of, or incorrect, numbered events throughout. 'Dealt with correctly' means that the activity starts from the correct event but need not necessarily finish at the correct event. For example, 'I dealt with correctly' requires the correct precedences for this activity, i.e. D, E, F and H labelled correctly **and** that they lead directly into the same node (possibly with the aid of a dummy activity). Activity I then starts from that node but ignore the end event for I. The table below is useful in checking this. **Activity on node is M0**

Activity	A	B	C	D	E	F	G	H	I	J	K	L	M
IPA	-	-	-	A	A	A, B, C	C	G	D, E, F, H	I	I	I	L

If an arc is not labelled, for example, if the arc for activity E is not labelled (but the arc is present) then this will lose the first A mark and the final (correct solution only) A mark – they can still earn the second A mark on the bod (benefit of doubt). If two or more arcs are not labelled then mark according to the scheme. Assume that a solid line which has not been labelled is an activity rather than a dummy (even if in the correct place for where a dummy should be)

Ignore incorrect or lack of arrows on the activities for the first four marks only

a1M1: Eight activities (labelled on arc), one start and at least two dummies placed

a1A1: Activities A, B, C, 1st two dummies, D, E and G dealt with correctly. The first two dummies are those at the end of activities A and C. Both dummies must have arrows pointing in the correct direction

a2A1: Activities F, H and 3rd dummy dealt with correctly. The 3rd dummy is the one at the end of D. The dummy must have an arrow pointing in the correct direction

a3A1: Activities I, J, K, L and M dealt with correctly

a4A1: CSO – all arrows correctly placed for each activity with one finish and a 4th dummy (with a correct arrow) at the end of activity J. **Please check all arcs carefully for arrows – if there are no arrows on any dummies then M1 only. Note that additional (but unnecessary) 'correct' dummies that still maintain precedence for the network should only be penalised with the final A mark, if earned, in (a)**

Note additional valid solutions:

- Activities D and E interchanged **or** J and K interchanged (or both)
- The dummy at the end of D could appear before activity D, similarly for the dummy at the end of J
- A combination of both these points, e.g. D and E interchanged and the corresponding dummy appearing before the activities
- The arrow on the 'final' dummy (the one at the end of J) could be reversed

b1M1: CAO (Activity I **only**) – if more than one activity stated as being critical then M0

b1A1: Correct reasoning – mention that every/all paths/routes (in the network) contain activity I e.g. 'there is no route that doesn't contain I' scores M1A1. Must mention 'path', 'route' etc. so e.g. 'everything passes through I' would score M1A0 (but 'every route passes through I' is fine for both marks)



c1B1: Correct answer only (12)

c2B1: Correct answer only (C G H I L M)

Question Number	Scheme	Marks
7.(a)	If CD is not in the tree then AD must be as these are the only two arcs incident to D or the weight of CD is greater than the weight of AD	M1
	$2y + x > 3y - 7 \Rightarrow y < x + 7^*$	A1 (2)
(b)	$4x + 1 < 2y + 1 \Rightarrow y > 2x^*$	B1
	$4x + 1 < 8x - 3 \Rightarrow x > 1$	B1
	$4x + 1 < 3y - 7 \Rightarrow 3y > 4x + 8$	B1 (3)
(c)		B1
		B1
		B1
		B1 (4)

5. (a)	e.g.	M1 A1 A1 A1 A1 (5)
(b)(i)	24 (hours)	B1
(b)(ii)	C, F, I and J	B1
(b)(iii)	Total float for G is 3 (hours)	B1
	Total float for K is 1 (hour)	B1 (4)
9 marks		

Notes for Question 5

Condone lack of, or incorrect, numbered events throughout. ‘Dealt with correctly’ means that the activity starts from the correct event but need not necessarily finish at the correct event, e.g. ‘D dealt with correctly’ requires the correct precedences for this activity, i.e. A and B labelled correctly and leading into the same node and D starting from that node but do not consider the end event for D. **Activity on node is M0**

If an arc is not labelled, for example, if the arc for activity C is not labelled (but the arc is present) then this will lose the first A mark and the final (CSO) A mark – they can still earn the second A mark on the bod. If two or more arcs are not labelled then mark according to the scheme. Assume that a solid line is an activity which has not been labelled rather than a dummy (even if in the correct place for where a dummy should be)

Ignore incorrect or lack of arrows on the activities for the first four marks only

a1M1: At least eight activities (labelled on arc), one start and at least two dummies placed

a1A1: Activities A, B, C **and** two of activities D, E, F or G dealt with correctly (so at least one dummy (+ correct arrow) required)

a2A1: Activities D, E, F and G dealt with correctly – so first two dummies (+ correct arrows) are required for this mark

a3A1: Activities H and I dealt with correctly (so must have the final two dummies + correct arrows)

a4A1: cso – activities J and K dealt with correctly. All arrows correctly placed for each activity with one finish and at most four dummies. Note that some candidates are drawing the graph non-planar which is fine

Please check all arcs carefully for arrows – if there are no arrows on any dummies then M1 only.

Note that additional (but unnecessary) ‘correct’ dummies that still maintain precedence for the network should only be penalised with the final A mark if earned

bi1B1: cao (24)

bii1B1: cao (C, F, I and J with no others)

biii1B1: cao (total float for G as 3)

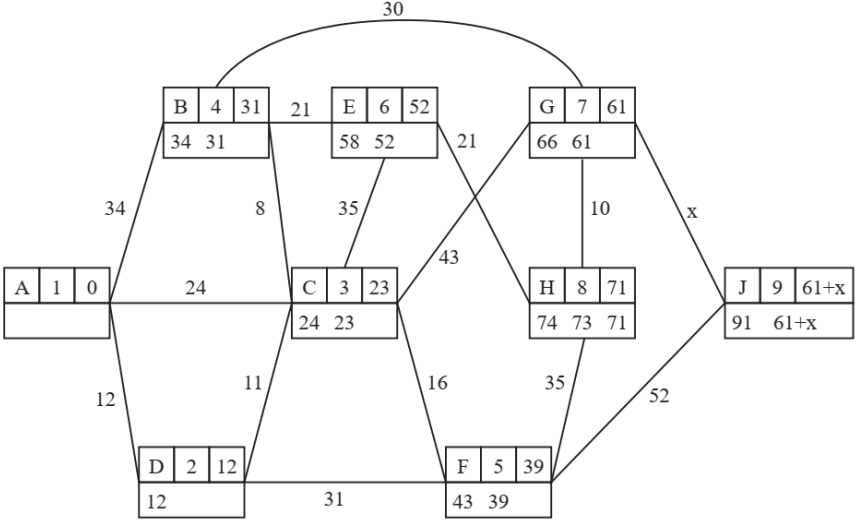


biii2B1: cao (total float for K as 1)

Useful for checking (a):

Activity	A	B	C	D	E	F	G	H	I	J	K
IPA	-	-	-	A, B	A, B	B, C	B, C	D	D, E, F, G	H, I	D, E, F



6.(a)	 Fastest time: 71 (minutes) Quickest route: ADCBGH	M1 A1 (DCB) A1 (FE) A1ft (GH) A1ft A1 (6)
(b)	$AD + EH = 12 + 21 = 33^*$	M1 A1
	$A(DCB)E + D(CBG)H = 52 + 59 = 111$	A1
	$A(DCBG)H + D(CB)E = 71 + 40 = 111$	A1
	$(383 + x) + 33 \dots 440 \text{ } x \dots$	depM1
	$24,, x < 30$	A1 (6)
(c)	e.g. ABCEBGCDADFGHEHFCA	B1 (1)
(d)	If a direct road DH opens then only A and E are odd therefore the shortest inspection route is $(383 + x) + 25 \text{ (DH)} + 52 \text{ (AE)}$	M1
	$460 + x = 488$ therefore $x = 28$	A1 (2)
		15 marks
Notes for Question 6		
In (a) it is important that all values at each node are checked very carefully – the order of the working values must be correct for the corresponding A mark to be awarded e.g. at H the working values must be 74 73 71 in that order (so 74 71 73 is incorrect) It is also important that the order of labelling is checked carefully. The order of labelling must be a strictly increasing sequence – so 1, 2, 3, 3, 4, ... will be penalised once (see notes below) but 1, 2, 3, 5, 6, ... is fine. Errors in the final values and working values are penalised before errors in the order of labelling		

Question Number	Scheme	Marks
2.(a)		M1 A1 M1 A1 (4)
(b)	e.g.	M1 A1 A1 A1 (4)
(c)	Lower bound is 4 workers e.g. activities K, M, N and Q together with $20 < \text{time} < 21$	M1 A1 (2)
		10 marks

Question Number	Scheme	Marks
Notes for Question 2		
a1M1: All top boxes complete (condone lack of 0 for the M mark only), values generally increasing in the direction of the arrows (so generally going from ‘left to right’ across the network), condone one ‘rogue’ value (if values do not increase in the direction of the arrows then if one value is ignored and the remaining values do increase in the direction of the arrows then this is considered to be a single rogue value). Note that all values in the top boxes could be incorrect but it can still score the M mark if the values are increasing in the way stated above a1A1: CAO – all values correct in the top boxes a2M1: All bottom boxes complete (but condone a blank box for the late event time at the end of activities P/Q and/or at the start node for this method mark only). Values generally decreasing in the opposite direction of the arrows (so generally going from ‘right to left’ across the network), condone one ‘rogue’ (as described above in a1M1) a2A1: CAO – all values correct in the bottom boxes Note that in (b) it is acceptable for the critical activities (C, E, G, J, N and P) to appear on separate lines or for several activities to appear on the same line as long as their durations and total floats are clear and do not overlap. The floats on the non-critical activities do not need to be shaded but they must be clearly distinguishable from the duration of the activity b1M1: At least ten different activities labelled including at least six floats. A scheduling diagram (so a diagram in which no floats are evident) scores M0 b1A1: The critical activities dealt with correctly and appearing just once (C, E, G, J, N and P) and three non-critical activities dealt with correctly (both duration and total float correct) b2A1: Any six non-critical activities correct (this mark is not dependent on the previous A mark) b3A1: CSO – completely correct Gantt chart (exactly sixteen activities appearing just once) c1M1: Either a statement with the correct number of workers (4) and stating the correct activities (K, M, N and Q) with any numerical time stated or the correct number of workers (4) and a time in the interval $20 \leq x \leq 21$ – mark the numerical value only not their use of the words ‘day/time’ (or equivalent) c1A1: A completely correct statement with details of both time and activities. Candidates must give a time within the correct interval of $20 < t < 21$, e.g. 20.5 and state the correct activities (K, M, N and Q). Please note the strict inequalities for the time interval (e.g. implying a time of 20 is incorrect). Answers given as an interval of time are acceptable provided the time interval stated is correct for all its possible values (e.g. time 20 – 21 is A0). A completely correct statement with an additional incorrect statement scores A0 (so do not ignore subsequent working)		

Question Number	Scheme	Marks																					
3.(a)	<table><tr><th>a</th><th>b</th><th>Qn</th></tr><tr><td>1</td><td>0.967168(21)</td><td>N</td></tr><tr><td>0.967168(21)</td><td>0.972789(34)</td><td>N</td></tr><tr><td>0.972789(34)</td><td>0.971833(85)</td><td>N</td></tr><tr><td>0.971833(85)</td><td>0.971996(47)</td><td>N</td></tr><tr><td>0.971996(47)</td><td>0.971968(80)</td><td>N</td></tr><tr><td>0.971968(80)</td><td>0.971973(50)</td><td>Y</td></tr></table>	a	b	Qn	1	0.967168(21)	N	0.967168(21)	0.972789(34)	N	0.972789(34)	0.971833(85)	N	0.971833(85)	0.971996(47)	N	0.971996(47)	0.971968(80)	N	0.971968(80)	0.971973(50)	Y	M1
	a	b	Qn																				
	1	0.967168(21)	N																				
	0.967168(21)	0.972789(34)	N																				
	0.972789(34)	0.971833(85)	N																				
	0.971833(85)	0.971996(47)	N																				
	0.971996(47)	0.971968(80)	N																				
0.971968(80)	0.971973(50)	Y																					
		A1																					
		A1																					
		A1																					
	Final output is 0.97197	(4)																					
(b)	Consideration of $12 - 5a$ being negative (oe)	M1																					
	$a > 2.4$	A1 (2)																					
		6 marks																					
Notes for Question 3																							
Candidates may write each value for a, b and N/Y (or No/Yes) in a new row which is fine. Assume that each row begins and ends when a value is changed. For example, the values in row 2 in the table above consists of the a value of 0.967168 and the b value of 0.972789. In (a) for the first three marks the values for a and b must be given to <u>at least</u> 6 decimal places (but accepted either rounded or truncated values) a1M1: At least three rows of cells for columns a and b completed with a correct first row (so 1 for a and 0.967168 for b) a1A1: CAO for the first three rows (for just the a and b columns) – to at least 6 dp a2A1: CAO for the fourth and fifth rows (for just the a and b columns) – to at least 6 dp a3A1: CSO - Output must be correct and written in the ‘Final Output’ box at the bottom of the page. This value must be given as 0.97197 (do not accept any other value). Candidates must have completed the third column of the table correctly to score this mark b1M1: Consideration that the fourth root cannot be negative – allow just stating the critical value of 2.4 for this mark or stating or implying one of $f(a) \leq 0$ or $f(a) = 0$ or $f(a) < 0$ where $f(a) = 12 - 5a \text{ or } f(a) = \frac{12 - 5a}{8} \text{ or } f(a) = (12 - 5a)^{\frac{1}{4}} \text{ or } f(a) = \left(\frac{12 - 5a}{8}\right)^{\frac{1}{4}}$ Allow any letter for a (e.g. x) b1A1: CAO (must be a strict inequality and must be using a)																							

Question Number	Scheme	Marks
	$\Rightarrow 3 + x + y + 3 = 26 - 10$ (oe)	
	$x + y = 10$ $-2x + y = 4$ and solve simultaneously to find both x and y	M1
	$x = 2, y = 8$	A1 (4)
(b)		M1 A1 A1 A1 (4)
(c)	Lower bound is 4 workers e.g. activities F, I, J and K together with $15 < \text{time} < 16$	M1 A1 (2)
10 marks		
Notes for Question 4		
a1B1: cao (any equivalent form) – allow $14 - y = 2(5 - x)$ or $14 - y = 10 - 2x$ a2B1: cao (any equivalent form) – allow $x + y + 6 = 16$ a1M1: Setting up two equations both including x and y (dependent on one correct equation) and an attempt to solve for both x and y leading to a value for x and a value for y – this mark can be implied if the candidate has two equations, both in x and y (with at least one correct), followed by values for x and y a1A1: cao ($x = 2, y = 8$) – if both correct values are stated without any working/justification please send to review		
b1M1: At least nine activities labelled including at least five floats. A scheduling diagram scores M0 b1A1: The critical activities dealt with correctly and appearing just once (A, G, I and L) and three non-critical activities dealt with correctly b2A1: Any six non-critical activities correct (this mark is not dependent on the previous A mark) b3A1: Completely correct Gantt chart (exactly thirteen activities appearing just once)		
c1M1: Either a statement with the correct number of workers (4) and the correct activities (F, I, J and K) with any numerical time (or time interval) stated or the correct number of workers (4) and a time in the interval $15 \leq t \leq 16$ – mark the numerical value only not their use of day/time. In either case they must state the correct number of workers. M0 for ‘F, J, K and the critical activity’ (they must explicitly state activity I in this case) unless a time in the interval stated above is given too c1A1: A completely correct statement with details of both time and activities. Candidates must give a time within the correct interval of $15 < t < 16$. Please note the strict inequalities for the time interval (e.g. implying a time of 15 is incorrect). Answers given as an interval of time are acceptable provided the time interval stated is correct for all its possible values (e.g. time 15 – 16 is A0). Note that ‘on day 16’ is correct but ‘on day 15’ is not correct. A completely correct statement with an additional incorrect statement scores A0 (so no isw)		

Question Number	Scheme	Marks
1. (a)		M1 A1 M1 A1 (4)
(b)	Activity H can be delayed by $23 - 9 - 4 = 10$ (days)	B1ft (1)
(c)	Lower bound = $\frac{5+7+6+\dots+6+5}{33} = \frac{79}{33} = 2.393\dots = 3$ workers	M1 A1 (2)
(d)	e.g. 	M1 A1 A1 (3)
		10 marks

Notes for Question 1

a1M1: All top boxes complete, values generally increasing in the direction of the arrows (so generally going from 'left to right' across the network), condone one 'rogue' value (if values do not increase in the direction of the arrows then if one value is ignored and the remaining values do increase in the direction of the arrows then this is considered to be a single rogue value). Note that all values in the top boxes could be incorrect but it can still score the M mark if the values are **increasing** in the way stated above

a1A1: CAO – **all** values correct in the top boxes

a2M1: All bottom boxes complete (but condone a blank box for the late event time at the end event node and/or no zero value for the late event time at the start event node for the **M** mark only). Values generally decreasing in the opposite direction of the arrows (so generally going from 'right to left' across the network), condone one 'rogue' (as described above in **a1M1**)

a2A1: CAO – **all** values correct in the bottom boxes

b1B1ft: Correct calculation seen for their H (provided total float is non-negative). Correct answer or the correct answer following through the event times for H with no working seen scores **B0** – must see all three numbers in their calculation (e.g. $23 - 9 - 4 = 10$, or $9 + 4 = 13$, $23 - 13 = 10$, etc.)

c1M1: Attempt to find lower bound: (a value in the interval $[71 - 87]$ / their finish time) **or** (sum of all the activities / their finish time) **or** (as a minimum) an awrt 2.4

c1A1: CSO – requires the correct answer of 3 **and** either a **correct** calculation **or** awrt 2.4. An answer of 3 with no working scores no marks in this part

d1M1: Not a cascade chart. 4 workers used at most, at least 10 activities placed

d1A1: 4 workers. All 16 activities present just once. Condone at most **two** errors. An activity can give rise to at most three errors; one on duration, one on time interval and only one on IPA

d2A1: CAO – no errors, all 16 activities present just once.

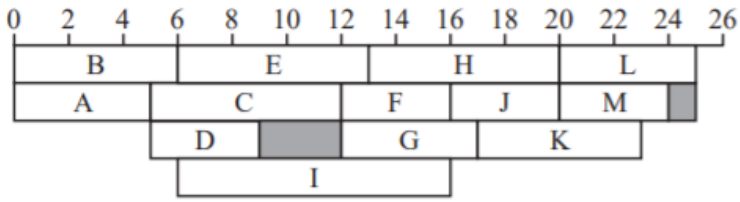
Activity	Duration	Time interval	IPA
A	5	0 – 11	-
B	7	0 – 7	-
C	6	0 – 16	-
D	4	7 – 11	B
E	5	11 – 16	A, D
F	6	7 – 16	B
G	2	7 – 16	B
H	4	9 – 23	C, G
I	2	16 – 30	C, E, F, G
J	7	16 – 23	C, E, F, G
K	5	23 – 30	H, J
L	4	23 – 27	H, J
M	8	23 – 33	H, J
N	3	28 – 33	I, K
P	6	27 – 33	L
Q	5	27 – 33	L

Question Number	Scheme	Marks
2. (a)(i)		M1 A1 M1 A1
(a)(ii)	Minimum completion time is 20 (days)	A1ft (5)
(b)	Lower bound = $\frac{59}{20} = 2.95 = 3$ workers	B1 (1)
(c)		M1 A1 A1 A1 (4)
		10 marks



	Notes for Question 2																																																												
ai1M1	All top boxes complete, values generally increasing in the direction of the arrows (‘left to right’), condone one rogue																																																												
ai1A1	CAO (top boxes)																																																												
ai2M1	All bottom boxes complete, values generally decreasing in the opposite direction of the arrows (‘right to left’), condone one rogue. Condone missing 0 and/or their 20 (at the end event) for the M mark only																																																												
ai2A1	CAO (bottom boxes)																																																												
aii3A1ft	Follow through the top value at the end node – dependent on both M marks – if labelled must be answered in the correct part of the question																																																												
b1B1	CSO – requires both a correct calculation or 2.95 seen and 3. An answer of 3 with no working scores no marks																																																												
c1M1	Not a cascade (Gantt) chart. 5 ‘workers’ used at most and at least 8 activities placed. End time must be the same as their end time from the diagram in (a)(i)																																																												
c1A1	3 or 4 workers. All 14 activities present (just once). Condone at most three errors. An activity can give rise to at most three errors; one on duration, one on time interval and only one on IPA																																																												
c2A1	3 or 4 workers. All 14 activities present (just once). Condone one error either precedence or time interval or activity length; An activity can give rise to at most three errors; one on duration, one on time interval and only one on IPA																																																												
c3A1	3 workers. All 14 activities present (just once). No errors.																																																												
For (c) the following may be useful in checking their schedule Note J and K are interchangeable																																																													
<table><tr><th>Activity</th><th>Duration</th><th>Time interval</th><th>IPA</th></tr><tr><td>A</td><td>5</td><td>0 – 5</td><td>-</td></tr><tr><td>B</td><td>4</td><td>0 – 12</td><td>-</td></tr><tr><td>C</td><td>7</td><td>0 – 11</td><td>-</td></tr><tr><td>D</td><td>4</td><td>5 – 9</td><td>A</td></tr><tr><td>E</td><td>3</td><td>5 – 12</td><td>A</td></tr><tr><td>F</td><td>3</td><td>9 – 12</td><td>D</td></tr><tr><td>G</td><td>2</td><td>9 – 17</td><td>D</td></tr><tr><td>H</td><td>4</td><td>9 – 18</td><td>D</td></tr><tr><td>I</td><td>6</td><td>12 – 18</td><td>B, C, E, F</td></tr><tr><td>J</td><td>7</td><td>7 – 18</td><td>C</td></tr><tr><td>K</td><td>7</td><td>7 – 18</td><td>C</td></tr><tr><td>L</td><td>3</td><td>11 – 20</td><td>G</td></tr><tr><td>M</td><td>2</td><td>18 – 20</td><td>G, H, I, J, K</td></tr><tr><td>N</td><td>2</td><td>14 – 20</td><td>K</td></tr></table>		Activity	Duration	Time interval	IPA	A	5	0 – 5	-	B	4	0 – 12	-	C	7	0 – 11	-	D	4	5 – 9	A	E	3	5 – 12	A	F	3	9 – 12	D	G	2	9 – 17	D	H	4	9 – 18	D	I	6	12 – 18	B, C, E, F	J	7	7 – 18	C	K	7	7 – 18	C	L	3	11 – 20	G	M	2	18 – 20	G, H, I, J, K	N	2	14 – 20	K
Activity	Duration	Time interval	IPA																																																										
A	5	0 – 5	-																																																										
B	4	0 – 12	-																																																										
C	7	0 – 11	-																																																										
D	4	5 – 9	A																																																										
E	3	5 – 12	A																																																										
F	3	9 – 12	D																																																										
G	2	9 – 17	D																																																										
H	4	9 – 18	D																																																										
I	6	12 – 18	B, C, E, F																																																										
J	7	7 – 18	C																																																										
K	7	7 – 18	C																																																										
L	3	11 – 20	G																																																										
M	2	18 – 20	G, H, I, J, K																																																										
N	2	14 – 20	K																																																										

Question Number	Scheme	Marks
6.(a)	e.g. 	M1 A1 (A B D I C F) A1 (E G H J) A1 (K L M) A1 (5)
(b)	Activities B, G, H and M are critical	B1 (1)
(c)	At time 9.5, activities G, C, E and I must all be happening therefore a minimum of 4 workers is required	M1 A1 (2)
(d)	$2 \leq x \leq 6$	B2, 1, 0 (2)
10 marks		
Notes for Question 6		
Condone lack of, or incorrect, numbered events throughout. ‘Dealt with correctly’ means that the activity starts from the correct event but need not necessarily finish at the correct event, e.g. ‘J dealt with correctly’ requires the correct precedences for this activity, i.e. F and G labelled correctly and leading into the same node and J starting from that node but do not consider the end event for J. Activity on node is M0		
If an arc is not labelled, for example, if the arc for activity F is not labelled (but the arc is present) then this will lose the first A mark and the final (CSO) A mark – they can still earn the second A mark on the bod. If two or more arcs are not labelled then mark according to the scheme. Assume that a solid line is an activity which has not been labelled rather than a dummy (even if in the correct place for where a dummy should be). Ignore missing arrows on the activities for the first four marks only		
a1M1	Nine activities (labelled on arc), one start and at least two dummies placed	
a1A1	Activities A, B, D, 1 st two dummies (including correct arrows), I, C and F dealt with correctly	
a2A1	Activities E, G, H and J dealt with correctly	
a3A1	Activities K, L and M dealt with correctly (so dummy at the end of I required + arrow)	
a4A1	CSO – all arrows correctly placed for each activity with one finish and exactly four dummies (so uniqueness dummy for K/M required)	
Please check all arcs carefully for arrows – if there are no arrows on any dummies then M1 only. Note that additional (but unnecessary) ‘correct’ dummies that still maintain precedence for the network should only be penalised with the final A mark if earned. Note that this answer is not unique		
b1B1	CAO (B, G, H and M and no others)	
c1M1	Either a statement with the correct number of workers (4) and stating the correct activities (G, C, E and I) with any numerical time stated or the correct number of workers (4) and a time in the interval $9 \leq t \leq 10$ – mark the numerical value only not their use of the words ‘day/time’ (or equivalent)	
c1A1	A completely correct statement with details of both time and activities. Candidates must give a time within the correct interval of $9 < t < 10$, e.g. 9.5 (or ‘on/during hour 10’) and state the correct activities (G, C, E and I). Please note the strict inequalities for the time interval (e.g. implying a time of 10 is incorrect). Answers given as an interval of time are acceptable provided the time interval stated is correct for all its possible values (e.g. time 9 – 10 or ‘between 9 and 10’ is A0). A completely correct statement with an additional incorrect statement scores A0 (so do not ignore subsequent working)	
d1B1	For either $x \geq 2$ or $x \leq 6$ (must be x not L)	
d2B1	CAO ($2 \leq x \leq 6$) – SC in (d) B1B0 for $2 < x < 6$	

Question Number	Scheme	Marks																																
4. (a)	<table><tr><th>Activity</th><th>IPA</th></tr><tr><td>A</td><td>-</td></tr><tr><td>B</td><td>-</td></tr><tr><td>C</td><td>A</td></tr><tr><td>D</td><td>A</td></tr><tr><td>E</td><td>A, B</td></tr></table> <table><tr><th>Activity</th><th>IPA</th></tr><tr><td>F</td><td>C</td></tr><tr><td>G</td><td>C</td></tr><tr><td>H</td><td>C, D, E</td></tr><tr><td>I</td><td>A, B</td></tr><tr><td>J</td><td>A, B</td></tr></table> <table><tr><th>Activity</th><th>IPA</th></tr><tr><td>K</td><td>F</td></tr><tr><td>L</td><td>F, G, H, I</td></tr><tr><td>M</td><td>F, G, H, I, J</td></tr></table>	Activity	IPA	A	-	B	-	C	A	D	A	E	A, B	Activity	IPA	F	C	G	C	H	C, D, E	I	A, B	J	A, B	Activity	IPA	K	F	L	F, G, H, I	M	F, G, H, I, J	B2, 1, 0 (2)
Activity	IPA																																	
A	-																																	
B	-																																	
C	A																																	
D	A																																	
E	A, B																																	
Activity	IPA																																	
F	C																																	
G	C																																	
H	C, D, E																																	
I	A, B																																	
J	A, B																																	
Activity	IPA																																	
K	F																																	
L	F, G, H, I																																	
M	F, G, H, I, J																																	
(b)	$v = 7, w = 4, x = 6, y = 16, z = 19$	B3, 2, 1, 0 (3)																																
(c)	$\frac{74}{25} = 2.96$ so 3 workers	B1 (1)																																
(d)	e.g. 	M1 A1 A1 (3)																																
(e)	New minimum project completion time: 27 (days)	B1																																
	Critical path: ACFK	B1 (2)																																
		11 marks																																
Notes for Question 4																																		
a1B1: Any 6 rows correct (not including A and B) a2B1: cao (condone blank rows for A and B) b1B1: Any 2 correct values b2B1: Any 3 correct values b3B1: All 5 values correct c1B1: cao (3 from correct working) – as a minimum for correct working accept either 2.96 or $\frac{5 + 6 + 7 + 4 + 7 + 4 + 5 + 7 + 10 + 4 + 6 + 5 + 4}{25}$ or $\frac{74}{25}$ d1M1: Not a cascade chart. 4 workers used at most, at least 9 activities placed d1A1: 4 workers. All 13 activities present (just once). Condone two errors either precedence or time interval or activity length. An activity can give rise to at most three errors; one on duration, one on time interval and only one on IPA d2A1: 4 workers. All 13 activities present (just once). No errors e1B1: cao (27 only) e2B1: cao (ACFK or KFCA only)																																		

2.(a)	$x = 10$ $y = 7$ from $9 - 0 - 5 = 2(22 - 13 - y)$ (oe)	B1 B1 (2)
(b)		M1 M1 A1 (3)
(c)	Lower bound is 4 workers e.g. activities H, D, F and G together with $11 < \text{time} < 12$	M1 A1 A1 A1 depM1 A1 (6)
		11 marks
Notes for Question 2		

a1B1: cao for x (ignore working for this mark)

a2B1: cao with sufficient working as Answer Given – as a minimum accept $4 = 2(9 - y)$ (oe) but just $4 = 18 - 2y$ is B0

b1M1: All top boxes complete, values generally increasing in the direction of the arrows (so generally going from ‘left to right’ across the network), condone one ‘rogue’ value (if values do not increase in the direction of the arrows then if one value is ignored and the remaining values do increase in the direction of the arrows then this is considered to be a single rogue value). Note that all values in the top boxes could be incorrect but it can still score the M mark if the values are **increasing** in the way stated above

b2M1: All bottom boxes complete. Values generally decreasing in the opposite direction of the arrows (so generally going from ‘right to left’ across the network), condone one ‘rogue’ (as described above in **b1M1**)

b1A1: cao – all values correct

c1M1: At least ten different activities labelled including at least seven floats. A scheduling diagram (so a diagram in which no floats are evident) scores M0

c1A1: The critical activities dealt with correctly and appearing just once (C, H and N) and three non-critical activities dealt with correctly (both duration and total float correct)

c2A1: Any six non-critical activities correct (this mark is not dependent on the previous A mark)

c3A1: cso – completely correct Gantt chart (exactly fourteen activities appearing just once)

c2dM1: Dependent on first M mark in this part. Either a statement with the correct number of workers (4) and stating the correct activities (H, D, F and G) with any numerical time stated **or** the correct number of workers (4) and a time in the interval 11,, t ,, 12 – mark the numerical value only not their use of the words ‘day/time’ (or equivalent)

c4A1: A completely correct statement with details of both time **and** activities. Candidates must give a time within the correct interval of $11 < t < 12$, e.g. 11.5 (or ‘on/during day 12’) and state the correct activities (H, D, F and G).

Please note the strict inequalities for the time interval (e.g. implying a time of 11 is incorrect). Answers given as an interval of time are acceptable provided the time interval stated is correct for all its possible values (e.g. time 11 – 12 or ‘between 11 and 12’ is A0). A completely correct statement with an additional incorrect statement scores A0 (so do not ignore subsequent working)

For (c) the following may be useful in checking their cascade chart provided the float is shown after the corresponding activity:

Activity	Duration + Float
A	0 to 4 F: 4 to 7
B	0 to 5 F: 5 to 9
C	0 to 7 Critical
D	4 to 12 F: 12 to 15
E	4 to 5 F: 5 to 9

Activity	Duration + Float
F	7 to 13 F: 13 to 15
G	7 to 13 F: 13 to 17
H	7 to 16 Critical
I	13 to 20 F: 20 to 22
J	13 to 15 F: 15 to 17

Activity	Duration + Float
K	16 to 21 F: 21 to 22
L	21 to 25 F: 25 to 26
M	16 to 19 F: 19 to 26
N	16 to 26 Critical

Question Number	Scheme	Marks
4.(a)(i)	The dummy from event 2 to event 3 is required because activity F (or G) relies on activity A and B but activity D (or E) relies on activity A only	B1
(ii)	The dummy from event 6 to event 7 is required as otherwise activities J and K (which both begin at event 4) would end at the same event	B1 (2)
(b)		M1 A1 M1 A1 (4)
(c)	Minimum completion time: 26 (hours) Critical activities: A, D, I and M	B1 B1 (2)
(d)	The early event time at event 7 is (the larger of) 12 or $9 + x$ The late event time at event 7 would then be either 15 or $9 + x$	M1 A1 A1 (3)
(e)	$x = 10$	B1 (1)
		12 marks

Notes for Question 4

In (a) any use of the terms ‘activity’ and ‘event’ must be correct

ai1B1: CAO dependency - all relevant activities must be referred to - activities A and B and one of D or E and one of F or G (so four activities) must be mentioned

aii1B1: CAO uniqueness – please note that, for example, ‘so that activities can be defined uniquely’ is not sufficient to earn this mark. There must be some mention of describing activities in terms of the event at each end. However, give bod on statements that imply that an activity begins and ends at the same event (for this mark candidates do not need to explicitly mention activities J and K)

b1M1: All top boxes complete, values in the top boxes generally increasing in the direction of the arrows (‘left to right’), condone one ‘rogue’ value (if values do not increase in the direction of the arrows then if one value is ignored and then the values do increase in the direction of the arrows then this is considered to be only one rogue value)

b1A1: CAO for the top boxes

b2M1: All bottom boxes complete, values generally decreasing in the opposite direction of the arrows (‘right to left’), condone one rogue. Condone missing 0 and/or their 26 (at the end event) for the M only

b2A1: CAO for the bottom boxes

c1B1: CAO (26)

c2B1: CAO (A, D, I and M only)



Question Number	Scheme	Marks
di1M1: One of 12 or $9 + x$ as the early event time for event 7 di1A1: Both correct answers 12, $9 + x$ (A0 if 'linked' in some way e.g. $12 > 9 + x$ but bod for the M mark) dii2A1: Both correct answers of 15, $9 + x$ for the late event time for event 7 e1B1: CAO (10)		

c3A1: CAO

Activity	Duration	Time interval	IPA
A	7	0 – 7	-
B	8	0 – 12	-
C	5	0 – 10	-
D	12	7 – 19	A
E	3	7 – 12	A
F	2	5 – 12	C
G	3	5 – 16	C
H	4	10 – 16	B, E, F
I	3	14 – 19	G, H
J	5	19 – 24	B, D, E, F, I
K	2	14 – 19	G, H
L	3	19 – 24	B, D, E, F, I, K
M	7	24 – 33	J, L
N	9	24 – 33	J, L
P	14	19 – 33	B, D, E, F, I, K

d1M1: D and P stated as being critical **or** activity G is not critical**d1A1:** Correct answer of D with fully correct reason (G not critical, D and P are both critical but D appears in both/all critical paths or P appears in only one critical path)

Question Number	Scheme	Marks
6. (a) and (b)		B1 B1 B1 (3) M1 A1 M1 A1 (4)
(c)	Critical activities: A, E, K, M, P	B1 (1)
(d)	Lower bound = $\frac{97}{28} = 3.46\dots$ so 4 workers	M1 A1 (2)
(e)	e.g. 	M1 A1 A1 (3)
		13 marks

Notes for Question 6

a1B1: Any two of the five arcs (G, H, I or the two dummies) drawn correctly (from correct vertex to correct vertex) – activities labelled with the correct letter (but condone no or wrong arrows) and the dummies must be shown as dashed lines (or labelled as ‘dummy’) with no weight (but condone no or wrong arrows)

a2B1: Four of the five arcs (G, H, I and the two dummies) drawn correctly – activities must be labelled with the correct letter (but condone no or wrong arrow) and the dummies must be shown as dashed lines (or labelled ‘dummy’) with no weight (but condone no or wrong arrows)

a3B1: CSO - all three activities (G, H and I) and the two dummies drawn correctly with no extras. Activities must be labelled with the correct letter and weights. The activities **and** dummies (as dashed lines with zero weight) must have the correct arrows (**do check carefully that all arrows are present**)

In (a) condone for full marks activities which are shown as dashed lines provided they are labelled with the correct letter. Condone lack of (or incorrect) weights on the activity arcs for the first two marks only.

b1M1: All top boxes complete (condone lack of 0 for the M mark only), values generally increasing in the direction of the arrows (‘left to right’), condone one ‘rogue’ value (if values do not increase in the direction of the arrows then if one value is ignored and the remaining values do increase in the direction of the arrows then this is considered to be a single rogue value). Note that all values in the top boxes could be incorrect but it can still score the M mark if the values are **increasing** in the way stated above – **this mark is dependent on the first mark having being awarded in (a)**

b1A1: CAO – all values correct in the top boxes

b2M1: All bottom boxes complete (condone lack of 28 and/or 0 for the M mark only), values generally decreasing in the opposite direction of the arrows (‘right to left’), condone one ‘rogue’ – **this mark is dependent on the first mark having being awarded in (a)**

b2A1: CAO – all values correct in the bottom boxes

For full marks in (b) all three activities (G, H and I) and the two dummies must have been added correctly in (a) – condone lack of arrows only. If all values in the bottom and top boxes are correct but any arc or dummy is missing or incorrect then award M1A1M1A0 – if all values are not correct (and some arcs are missing) then mark to the scheme above

c1B1: CAO (A, E, K, M, P only)

d1M1: Attempt to find lower bound: (a value in the interval [87 – 107] / their finish time) **or** showing the summing of **all** 15 activities divided by their finish time **or** (as a minimum) an awrt 3.5

d1A1: CSO – either a **correct** calculation seen **or** awrt 3.5 **then** 4 (with no incorrect working seen). An answer of 4 with no working scores M0A0

e1M1: Not a cascade (Gantt) chart. 5 ‘workers’ used at most and at least 11 activities placed

e1A1: 4 workers. All 15 activities present (just once). Condone at most two errors. An activity can give rise to at most three errors; one on duration, one on time interval and only one on IPA

e2A1: 4 workers. All 15 activities present (just once). No errors

Activity	Duration	Time	IPA
A	4	0 – 4	-
B	7	0 – 9	-
C	6	0 – 9	-
D	10	4 – 19	A
E	5	4 – 9	A
F	7	6 – 16	C
G	6	9 – 16	B, C, E
H	6	9 – 19	B, C, E

Activity	Duration	Time	IPA
I	7	9 – 28	B, C, E
J	9	15 – 28	D, H
K	8	9 – 17	B, C, E
L	4	17 – 28	F, G, K
M	6	17 – 23	F, G, K
N	7	15 – 23	F, G
P	5	23 – 28	M, N

Question number	Scheme	Marks																																										
4.(a)	<table><tr><th>Activity</th><th>Immediately preceded by</th><th>Activity</th><th>Immediately preceded by</th><th>Activity</th><th>Immediately preceded by</th></tr><tr><td>A</td><td>-</td><td>G</td><td>A, B, E</td><td>M</td><td>D, G</td></tr><tr><td>B</td><td>-</td><td>H</td><td>A, B, E</td><td>N</td><td>H, K</td></tr><tr><td>C</td><td>-</td><td>I</td><td>A, B, E</td><td>P</td><td>H, K</td></tr><tr><td>D</td><td>A</td><td>J</td><td>A, B, E, F</td><td>Q</td><td>H, I, J, K</td></tr><tr><td>E</td><td>C</td><td>K</td><td>D, G</td><td>R</td><td>P, Q</td></tr><tr><td>F</td><td>C</td><td>L</td><td>D, G</td><td></td><td></td></tr></table>	Activity	Immediately preceded by	Activity	Immediately preceded by	Activity	Immediately preceded by	A	-	G	A, B, E	M	D, G	B	-	H	A, B, E	N	H, K	C	-	I	A, B, E	P	H, K	D	A	J	A, B, E, F	Q	H, I, J, K	E	C	K	D, G	R	P, Q	F	C	L	D, G			B2, 1, 0 (2)
	Activity	Immediately preceded by	Activity	Immediately preceded by	Activity	Immediately preceded by																																						
	A	-	G	A, B, E	M	D, G																																						
	B	-	H	A, B, E	N	H, K																																						
	C	-	I	A, B, E	P	H, K																																						
	D	A	J	A, B, E, F	Q	H, I, J, K																																						
	E	C	K	D, G	R	P, Q																																						
F	C	L	D, G																																									
(b)		M1 A1 M1 A1 (4)																																										
(c)	Critical activities: C, E, G, K and N	B1 (1)																																										
(d)	Float on J = 35 – 22 – 5 = 8	B1ft (1)																																										
(e)	Lower bound is $\frac{133}{43} = 3.0930... = 4$	B1 (1)																																										
(f)	e.g. 	M1 A1 A1 A1 (4)																																										
		(13 marks)																																										

Notes for Question 4

a1B1: Any four (of the eight blank) rows correct

a2B1: All eight rows correct

b1M1: All top boxes complete, values generally increasing in the direction of the arrows (so generally going from 'left to right' across the network), condone one 'rogue' value (if values do not increase in the



direction of the arrows then if one value is ignored and the remaining values do increase in the direction of the arrows then this is considered to be a single rogue value). Note that all values in the top boxes could be incorrect but it can still score the M mark if the values are **increasing** in the way stated above

b1A1: CAO – **all** values correct in the top boxes

b2M1: All bottom boxes complete (but condone a blank box for the late event time at the end event node for the M mark only). Values generally decreasing in the opposite direction of the arrows (so generally going from ‘right to left’ across the network), condone one ‘rogue’ (as described above in **b1M1**)

b2A1: CAO – **all** values correct in the bottom boxes

c1B1: CAO (C, E, G, K and N only)

d1B1ft: correct calculation seen for their J (provided total float is non-negative). Correct answer or the correct answer following through the event times for J with no working seen scores B0 – must see all three numbers in their calculation

e1B1: CSO – 4 together with **either** a **correct** calculation seen **or** an awrt 3.1. An answer of 4 with no working scores B0. If working seen then it must be correct

f1M1: Not a cascade (Gantt) chart. 5 ‘workers’ used at most and at least 8 new (11 in total) activities placed

f1A1: 4 workers. All 14 new (17 in total) activities present (just once). Condone at most **three** errors. An activity can give rise to at most three errors; one on duration, one on time interval and only one on IPA

f2A1: 4 workers. All 14 new (17 in total) activities present (just once). Condone **one** error **either** precedence **or** time interval **or** activity length; An activity can give rise to at most three errors; one on duration, one on time interval and only one on IPA

f3A1: 4 workers. All 14 new (17 in total) activities present (just once). No errors.

The table below is helpful in checking an activities duration, time interval and IPA

Activity	Duration	Time interval	IPA
D	12	9 – 23	A
E	3	9 – 12	C
F	13	9 – 30	C
G	11	12 – 23	A, B, E
H	8	12 – 30	A, B, E
I	12	12 – 35	A, B, E
J	5	22 – 35	A, B, E, F
K	7	23 – 30	D, G
L	6	23 – 43	D, G
M	6	23 – 43	D, G
N	13	30 – 43	H, K
P	7	30 – 40	H, K
Q	5	30 – 40	H, I, J, K
R	3	37 – 43	P, Q

Question Number	Scheme	Marks
1. (a)		M1 A1 M1 A1 (4)
(b)	Activity D has a total float of $12 - 4 - 5 = 3$ (hours)	B1ft (1)
(c)	Lower bound = $\frac{4 + 3 + 7 + \dots + 5 + 12}{24} = \frac{67}{24} = 2.791\dots = 3$ workers	M1 A1 (2)
(d)		M1 A1 A1 A1 (4)
(e)	Minimum is 4 workers e.g. activities F, H, I and L together with $12 < \text{time} < 13$	dM1 A1 (2)
		13 marks
	Notes for Question 1	
a1M1	All top boxes complete, values generally increasing in the direction of the arrows ('left to right'), condone one rogue	
a1A1	CAO (top boxes)	
a2M1	All bottom boxes complete, values generally decreasing in the opposite direction of the arrows ('right to left'), condone one rogue. Condone missing 0 and/or their 24 (at the end event) for the M mark only	
a2A1	CAO (bottom boxes)	
b1B1ft	Correct calculation for their event times for activity D (all three figures must be seen)	

Question Number	Scheme	Marks
c1M1	Attempt to find lower bound: (a value in the interval [55 – 79] / their finish time) or (sum of the activities (12 values) [condone one missing value] / their finish time) or (as a minimum) an awrt 2.8	
c1A1	CSO – requires both a correct calculation or awrt 2.8 seen and 3. An answer of 3 with no working scores no marks	
d1M1	At least eight different activities labelled including at least five floats. A scheduling diagram (so a diagram in which no floats are evident) scores M0	
d1A1	The critical activities dealt with correctly and appearing just once (C, F, G and J) and three non-critical activities dealt with correctly (both duration and total float correct)	
d2A1	Any five non-critical activities correct (this mark is not dependent on the previous A mark)	
d3A1	CSO – completely correct Gantt chart (exactly twelve activities appearing just once)	
e1depM1	Dependent on M mark in (d). Either a statement with the correct number of workers (4) and stating the correct activities (F, H, I and L) with any numerical time stated or the correct number of workers (4) and a time in the interval $12 \leq t \leq 13$ – mark the numerical value only not their use of the words ‘day/time’ (or equivalent)	
e1A1	A completely correct statement with details of both time and activities. Candidates must give a time within the correct interval of $12 < t < 13$, e.g. 12.5 (or ‘on/during hour 13’) and state the correct activities (F, H, I and L). Project is measured in hours, so a time of (e.g.) 12:30 is acceptable. (Condone use of ‘days’ instead of ‘hours’) Please note the strict inequalities for the time interval (e.g. implying a time of 12 is incorrect). Answers given as an interval of time are acceptable provided the time interval stated is correct for all its possible values (e.g. time 12 – 13 or ‘between 12 and 13’ is A0). A completely correct statement with an additional incorrect statement scores A0 (so do not ignore subsequent working)	

For (d) the following may be useful in checking their cascade chart provided the float is shown after the corresponding activity:

Activity	Duration + Float	Activity	Duration + Float	Activity	Duration + Float
A	0 to 4 F: 4 to 7	F	7 to 13 Critical	K	13 to 18 F: 18 to 24
B	0 to 3 F: 3 to 13	G	13 to 18 Critical	L	9 to 21 F: 21 to 24
C	0 to 7 Critical	H	7 to 13 F: 13 to 18		
D	4 to 9 F: 9 to 12	I	7 to 13 F: 13 to 18		
E	4 to 6 F: 6 to 18	J	18 to 24 Critical		

Question Number	Scheme	Marks
7.(a)	Dummy is required to uniquely define Activity Q and Activity R	B1 (1)
(b)		M1 A1 M1 A1 (4)
(c)	A F I L P	B1 (1)
(d)	$28 - 13 - 12 = 3$ (days)	M1 A1 (2)
(e)		M1 A1 A1 A1 (4)
(f)	At time $12 < t < 13$ activities D, E, F, G and H must be happening. Therefore five workers required	M1 A1 (2)
		14 marks

Notes for Question 7		
a1B1	CAO – accept equivalent explanations (e.g. to allow two activities to start at the same event and end at the same event – see examples)	
b1M1	All top boxes complete, values generally increasing in the direction of the arrows ('left to right'), condone one rogue value which is a number in a top box greater than the subsequent value	
b1A1	CAO (top boxes)	
b2M1	All bottom boxes complete, values generally decreasing in the opposite direction of the arrows ('right to left'), condone one rogue value which is a number in a bottom box greater than the previous value. Condone missing 0 and/or their 41 (at the end event) for the M mark only	
b2A1	CAO (bottom boxes)	
c1B1	CAO	
d1M1	Their "Late End Time K" – "Early Start Time K" – 12 or a correct equivalent calculation e.g. $41 - 7 - 6 - 12 - 4 - 9 (= 3)$	
d1A1	CAO	
e1M1	Cascade Chart not a schedule. At least 11 activities including at least 6 floats	
e1A1	Critical activities (AFILP) correct and at least 3 non-critical activities correct	
e2A1	At least 9 non-critical activities correct	
e3A1	CAO All 17 activities present (just once). No errors.	
f1M1	Either a statement with the correct number of workers (5) and stating the correct activities (D, E, F, G and H) with any numerical time stated or the correct number of workers (5) and a time in the interval $12 \leq t \leq 13$ – mark the numerical value only not their use of the words 'day/time' (or equivalent)	
f1A1	A completely correct statement with details of both time and activities. Candidates must give a time within the correct interval of $12 < t < 13$, e.g. 12.5 (or 'on/during day 13') or $t \in (12, 13)$ and state the correct activities (D, E, F, G and H). (If using set notation there must be a statement linking time to (12, 13)) Please note inequalities for the time interval implying a time of 12 is incorrect. Answers given as an interval of time are acceptable provided the time interval stated is correct for all its possible values (e.g. time 12 – 13 or 'between 12 and 13' is A0). A completely correct statement with an additional incorrect statement scores A0 (so do not ignore subsequent working)	

Question	Scheme						Marks
7. (a)		Activity	IPA	Activity	IPA		B1 (DEFGH) B1 (IJK) B1 (LMN)
		A	-	H	B C		
		B	-	I	D E		
		C	-	J	F		
		D	A B	K	F		
		E	B	L	F G H		
		F	B	M	I J		
		G	B	N	K L		
(b)	<pre>graph LR Start["0 0"] -- "A(8)" --> Node1["12 12"] Start -- "B(12)" --> Node2["12 12"] Start -- "C(14)" --> Node3["14 16"] Node1 -.-> Node2 Node2 -- "D(6)" --> Node4["18 18"] Node2 -- "E(4)" --> Node4 Node2 -- "F(8)" --> Node5["20 21"] Node2 -- "G(8)" --> Node6["20 21"] Node3 -- "H(5)" --> Node6 Node4 -- "I(7)" --> Node7["25 25"] Node5 -- "J(2)" --> Node7 Node5 -- "K(6)" --> Node8["26 27"] Node6 -- "L(6)" --> Node8 Node7 -- "M(6)" --> End["31 31"] Node8 -- "N(4)" --> End</pre>						M1 A1 M1 A1

(c)	Lower bound = $(8+12+14+6+4+8+8+5+7+2+6+6+6+4)/31 = 96/31 = 3.1$ Therefore 4 workers required	M1 A1 (2)
(d)		M1 A1 A1 A1 (4)
(e)	At $13 < t < 14$ activities D, C, F and G must be happening and at $16 < t < 17$ activities D, E, G and H must be happening. Also activity E must be happening at either $13 < t < 14$ or $16 < t < 17$ so a total of five workers	M1 A1 A1
		(3)
(16 marks)		

Notes	
a1B1	Activities D, E, F, G and H correct
a2B1	Activities I, J and K correct
a3B1	Activities L, M and N correct
b1M1	All top boxes complete, values generally increasing in the direction of the arrows ('left to right'), condone one rogue value which is a number in a top box greater than the subsequent value
b1A1	CAO (top boxes)
b2M1	All bottom boxes complete, values generally decreasing in the opposite direction of the arrows ('right to left'), condone one rogue value which is a number in a bottom box greater than the previous value. Condone missing 0 and/or their 31 (at the end event) for the M mark only
b2A1	CAO (bottom boxes)
c1M1	Calculates $96 (+/-14)/31$ – a calculation using the sum of the activities (accept a total in the range 82 – 110) divided by their finish time or sight of awrt 3.1
c1A1	4 workers but must follow from a correct calculation (awrt 3.1) with no incorrect working seen (note an answer of 4 with no working is M0)
d1M1	Cascade Chart not a schedule. At least 9 activities including at least 5 floats
d1A1	Critical activities (BDIM) and at least 3 non-critical activities correct
d2A1	At least 7 non-critical activities correct
d3A1	CAO All 14 activities present (just once). No errors.
e1M1	A statement mentioning one of the following • 4 workers, 4 of D C E F G stated and time 13 – 14 • 4 workers, 4 of D E F G H stated and time 16 – 17 • 5 workers, either D C E F G or D E F G H stated and any time interval
e1A1	A correct statement of 5 workers with details of both the time and activities for one of the intervals. Candidates must give a time within one of the correct intervals. Either $13 < t < 14$, e.g. 13.5 (or 'on/during day 14') and state the correct activities D, C, E, F and G or $16 < t < 17$ (or e.g. 16.5 or 'on/during day 17') and the correct activities D, E, F, G and H. Please note an inequality for the time interval implying a time of 13, 14, 16 or 17 is incorrect. Answers given as an interval of time are acceptable provided the time interval stated is correct for all its possible values (e.g. time 13 – 14 or 'between 13 and 14' is A0)
e2A1	A fully correct statement mentioning both intervals and both correct groups of activities and stating 5 workers

